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PETROGRAPHIC INTERPRETATION OF GEOPHYSICAL DATA ON THE STRUCTURE OF THE EARTH'S CRUST[1,2]

by

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The structure of the earth's crust and the p-seated processes taking place within this ne is the basic subject matter of certain prob-natic questions in geology and, in particular, petrology. But these paramount and funda-ntal scientific problems, by virture of the in-essibility of the deep parts of the crust for ect observation, remain unsolved to this day.

One of the most important results of geologic owledge concerning the earth's surface is the lerstanding that, owing to tectonic and vol-nic (or more broadly — magmatic) processes, ologists can study directly material objects deep-seated origin. An example would be gmatic rocks or objects which once occurred plutonic environments, e. g., deep-seated etamorphic zones of the Precambrian, espe-lly in folded regions.

Such generalizations as geologic, tectonic and her maps, as well as theoretical conclusions out the evolution of geosynclines, magmatic ferentiation and the magmatic associations of neous rocks connected by their "consanguinity", d the paragenesis of elements, minerals and cks permits one to depict, with sufficient jectivity, the structure and the basic features the development of the crust into continents ring the geologic part of the earth's history a planet.

The base of most contemporary platforms is mposed of strongly metamorphosed rocks of e Precambrian, with a considerable develop-ent of granitic complexes. In view of its com-exity, the geologic history of the Precambrian s not yet been sufficiently clarified, but at y rate, one may presume the Precambrian age of the earth's development to have occurred t less than 2 to 2. 5 billion years ago.

It is necessary to emphasize the duration, complexity and multi-phase nature of the develop-ment of the earth's crust; some parts were in a relatively quiet condition for a long time (i. e., hundreds of millions of years), having undergone only gradual uplifts and submergences (e. g., the Russian platform in post-Proterozoic time), while other parts, such as the regions of ancient fold-ing (e. g., the Urals) or of younger folding (e. g., the Caucasus — part of the Mediterranean Tethys region), were zones in which the crust was in an mobile condition for long periods.

At the present time, on the basis of sufficiently reliable geologic facts and data from absolute-age determinations by radiologic methods, the duration of the development of these folded re-gions is believed to be 1 billion years for the Urals and 0. 5 billion years for the Caucasus. Situated between platform areas, these regions of active folding experienced a complex history of uplifts and deep submergences, accompanied by the repeated renewal of folding and magmatic processes (both extrusive and intrusive).

Relentlessly investigating the pages of the geologic chronicle that are revealed in varying degrees of erosion and denudation, and taking into account the results of the application of modern methods, geology has produced some basic concepts about patterns of development of the crust.

It is known that marine deposits occur almost everywhere on the present continents, conse-quently these continents must have repeatedly sunk below ocean level. Some continental struc-tures are truncated by the shoreline of seas and oceans and extend into the region now covered by waters of seas and oceans. Hence, it is natural to assume that if the continents were covered by oceans, then the ocean bottoms were also once continents. Fossilized and recent faunas permit one to infer that during certain epochs there existed rather narrow links be-tween the continents in the form of continental areas which have now disappeared beneath the ocean. There are also data about the removal of terrigenous material from the side of the present oceans, which is only possible if a re-gion under erosion has once existed there.

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[1]O petrograficheskom interpretatsii geofizicheskikh nnykh o Stroyenii Zemnoy kory.

[2]Paper at the general meeting of the Department of ological and Geographical Sciences of the Academy Sciences, U. S. S. R., February 24, 1960.

But as regards those parts of the earth covered by oceans, then here the store of geologists' knowledge about the structure of the crust consists of fragmentary data on the geologic structure of oceanic islands and information about bottom sediments and the topography of the ocean bottom. In the last 20 or 25 years important geophysical data have been gathered about seismic velocities and gravity anomalies in different parts of the crust. But in the main this material has, naturally, only an indirect geologic significance. And the direct geologic basis for opinions concerning the structure of the earth's crust in continental and oceanic regions is, no doubt, immeasurable.

GENERAL DATA OF GEOPHYSICS AND GEOLOGIC CONCLUSIONS FORMULATED FROM THEM ABOUT THE STRUCTURE OF THE EARTH'S CRUST

Generalizations from the most recent geophysical and other data on the structure of the earth's crust and the resulting geologic concepts were brough to light in a special series of articles entitled Crust of the Earth, published by the Geological Society of America in 1955.

In recent years the results of geophysical investigations in many regions of the crust have been published in a number of other publications [34, 37]. The latest data of R. Raitt, J. Ewing and F. Press [33, 46, 49] were presented at the Ocenographic Congress of 1959 in the U. S. A.

At the present time, as a result of much effort and expediture on all the geophysical investigations of the passage of elastic waves caused by special explosions, or on the study of seismic waves caused by earthquakes, and also on studies of gravity anomalies, there remains no doubt about the fact that elastic waves in the earth's crust have different velocities of propagation; on the basis of this two crustal types are distinguished — continental and oceanic.

The Mohorovicic discontinuity is present everywhere in the earth's crust, being characterized by the definite and rapid change in the acceleration of elastic waves from 7 to 8 km/sec. It has been shown that beneath the present continents this discontinuity occurs at an average depth of 30 to 40 km and beneath the abyssal parts of oceans at an average depth of about 10 km, which includes the approximately 5 km thickness of the column of ocean water.

Unlike many geophysicists, B. Gutenberg [13, 36], in an article on the velocities of propagation of seismic waves within the crust, notes first and foremost that he understands the lithosphere to occur beneath the "crust", assigning the Mohorovicic discontinuity to the crust itself. While generalizing on the data relating to the crust of continents, which, in his opinion, is still inadequate, B. Gutenberg draws the following conclusions.

There is a layer beneath the sedimentary rocks in which the velocity of propagation of longitudinal waves is about 6 km/sec., while that of transverse waves is about 3.6 km/sec. In this layer the velocity increases at least to a depth of 10 km. At depths of between 10 and 20 km, no layer boundaries are revealed either by reflected or refracted waves.

In addition, B. Gutenberg notes that reflections were detected from a depth of between 20 and 25 km during the recording of large explosions in Wyoming (U. S. A.), Southern California, and Southern Germany. He considers that this depth corresponds to the "Conrad boundary", and that the velocity of longitudinal waves below the Conrad boundary is 6.5 to 7 km/sec, the velocity of transverse waves being 3.6 km/sec. It is considered that the layer occurring below the Conrad boundary consists of basalt (gabbro); the lower boundary of this layer is the Mohorovicic discontinuity.

B. Gutenberg notes that there is no single opinion regarding the composition of rocks below the Mohorovicic discontinuity. The presence is assumed of such rocks as dunite or peridotite, and Leis in particular suggests the possibility of a phased transition at the Mohorovicic discontinuity. But at the same time, according to B. Gutenberg, an explanation is also required as to why such a transition takes place at a depth of about 10 km beneath the oceans, and at a depth of 50 km on the continents (beneath certain alpine regions).

B. Gutenberg allows for the possibility of composite effects on the velocity of motion of elastic waves because these velocities, as known from admittedly inadequate experimental data, increase with increasing pressure but decrease with increasing temperature. To the latter may be added other decreases connected with the nearness of that depth at which the phased transition of matter may take place. Hence follows the possibility of there being a complex relationship between the velocities of elastic waves and depth, which is especially important for depths of from ±10 to 100 km and more. At a depth of 60 to 70 km in the continental crust, the velocity of elastic waves is reduced.

On the basis of strictly selected geophysical data, M. Ewing and F. Press [28] arrive at the following conclusions.

The continental crust and underlying mantle are identical wherever they have been studied. The oceanic crust is also very similar to the underlying shell.

In addition, the authors distinguish three

es of anomalous crust, developed in the form narrow bands: a) mountain ranges, both con-ental and also submarine; b) island arcs and ep submarine trenches; c) continental margins : found in either oceanic or continental parts the crust. In particular the authors write: every case, without any exception, it is re-gnized that the crust possesses typical con-ental properties in large areas occupied by ayer of water with a thickness of 1000 fathoms 320 m), while it has typical oceanic properties ere the water layer is more than 2000 fathoms 640 m) thick" ([28], p. 15).

In continental regions the crust has a thick-ss of 30 to 40 km, and the velocity of elastic ves within it is: a) $V_p = 6.2$ and $V_s = 3.6$ /sec. near the surface; b) the velocity in-eases with depth, V_p up to 7.05 and V_s up 3.8 km/sec. In rocks of the underlying shell $= 8.15$ and $V_s = 4.7$ km/sec.

The oceanic crust is characterized by the ct that the Mohorovicic discontinuity occurs at depth of 10 to 11 km below sea level and "is derlain by ultrabasic rocks (my underlining, A.) with a velocity for the longitudinal waves about 8.1 km/sec. (in the range 7.9 to 8.2 n/sec)". The oceanic crust consists of a yer of basic rocks (my underlining, G. A.) th a velocity in the range 6.4 to 6.9 km/sec. non-consolidated or semi-consolidated layer sediments with a thickness of less than 1 km erlies the crust in the oceans. According these authors, the crust beneath the Gulf of exico, the Carribean Sea and the Mediterranean a belongs to the oceanic rather than to the con-nental type.

It follows from these generalizations that, espite the colossal pressures in each separate art of the crust, which increase with depth, e velocity of longitudinal waves in the con-nental crust with a thickness as much as 40 m increases from 6.2 to 7.05 km/sec.

Kh. Teytl and M. T'yuv [24-a], in a paper eismic investigations of the continental crust, rite: "The velocity increases only slightly ith depth in the upper two-thirds of the crust aving a typical structure. Within the lower hird part of the crust the velocity increases nore rapidly, perhaps at times, till it attains he value of 8 km/sec that is characteristic f the upper part of the shell. The increase in elocity is either restricted to the special efractive-focusing zone extending to a depth f some kilometers, or else it takes place vith a jump within a small fraction of this latter lepth, from a value of 7 to 8 km/sec (p. 64)". n other words the velocity of 6.2 to 6.4 km/sec or the granite layer differs very little from the velocity in the "basalt" layer of the oceanic crust 6.4 to 6.9 km/sec according to J. Ewing).

In the short theses of the reports prepared at the International Oceanographic Congress of 1959 in the U.S.A., basic conclusions are published on the state of our knowledge of the structure of the crust according to geophysical data.

On the basis of studies of seismic waves from nuclear explosions in the area of Bikini and Eniwetok atolls, D. Garder [35], in the résumé of his paper on the structure of the crust beneath the western part of the Pacific Ocean, points out that the depth of the Mohorovicic discontinuity here is about 18 km and that the crustal structure beneath the islands approximates the continental type.

R. Raitt and G. Shor [47], in their paper Crust of the Pacific Ocean, point out that the study of seismic waves may allow a four-layer structural model of the crust, constructed with velocities for the various layers of 2, 5, 6.8 and 8.2 km/sec. A variation in the thickness of the layers is observed during the examination of the seismic waves, but the exceptional cases are associated with such topographic features of the bottom as submarine ranges and trenches. The study of such anomalies leads to remarkably similar results. The average thickness of the ocean crust is about 6 km, which favors the establishment of the isostatic equilibrium of the continental and ocean crusts. According to these authors, this is the cause of the correlation between the depth of the bottom and the thickness of the crust. In their paper Ranges and prominences of the Pacific Ocean, the same authors [50] note that seismic profiles reveal a structure of the ranges and prominences which is not compatible on the whole with that of either the continental or oceanic crust.

In many places the East Pacific prominence has an oceanic crust with a normal or reduced thickness. But the velocities in the underlying material are abnormally low for the mantle. The Tonga Range consists of thick sediments and volcanic layers which are superimposed on oceanic crust of a normal thickness, but the velocity of longitudinal waves in the material underlying the ocean crust is 7 to 7.8 km/sec.

The Hawaiian Range possesses a core of material through which waves travel with a velocity of 6.75 km/sec. The core extends almost to the level of the surrounding ocean bottom, and the crust, with $V = 6.75$ km/sec, thickens below the sea bed, the Mohorovicic discontinuity also being depressed (to what depth is not indicated, G.A.). According to these authors, a similar picture is observed in the Aleutian Range.

The causes of the difference between the oceanic and continental crust are the subject of scientific discussion. In order to solve this problem, a project involving "a borehole through the crust" in the ocean has been worked out in the U.S.A. In a memorandum based on this project, it is pointed out that there is no other

way whatever of obtaining precise scientific data on the composition, age and physical properties of the mantle and deep rocks of the crust. In the same place it is said that "the earth is believed to consist of two main zones: a core of Ni + Fe and a mantle of material resembling peridotite. But nobody is completely confident about this. Above the mantle lies a slag-like cover formed of lighter rocks (the crust), and only this latter part is accessible to direct observation."

It is also pointed out in the report that the actual nature of the Mohorovicic discontinuity is the subject of scientific discussion. It may take the form of either an abrupt or, on the contrary, a gradual transition. Existing seismic methods are not capable of penetrating within approximately half a kilometer of this discontinuity. The composition of the underlying mantle is not known.

In order to produce an accurate approach to the interpretation of geophysical data, there are important facts to consider concerning the history of the oceans.

In a paper by A. Pol'dervaart [19], who also considers the Mohorovicic discontinuity to be the boundary between the crust and the ultrabasic subcrustal shell, some data are quoted relating to the oceans.

He draws the conclusion that the hydrosphere was initially formed at the beginning of the geologic history of the earth. Its formation was connected with the condensation of water vapor from the ancient atmosphere arising from the degasification of the depths of the earth, as well as with the solvent action of water during weathering and hydrothermal rock alteration. In his opinion the fact of the hydrosphere's development in the course of geologic time is firmly established.

A. Pol'dervaart cites data about the balance between water and mineral matter in the ocean: the total volume of ocean water is $1370 \cdot 10^6$ km^3, the total mass of matter dissolved in the ocean being $56 \cdot 256 \cdot 10^{12}$t. Pol'dervaart states that, according to Murray, $4877 \cdot 10^6$ tons of fresh solubile matter are added to the ocean in a year. Hence, if one assumes the salinity of the ocean to have increased during geologic time from almost fresh water up to the present-day level, then, considering the available volume of water and the above-cited amount of soluble substances added each year, the present-day concentration of soluble matter in the oceans of the world could have been formed in 12 million years.

One should mention the data given in this paper on the present-day equilibrium of aqueous masses. Over the ocean, the total amount of sediment is $297 \cdot 10^3$ km^3, while the total evaporation is $384 \cdot 10^3$ km^3. Over dry land, however, sedimentation exceeds evaporation. The excess of sediments over evaporation in terrestial regions $37 \cdot 10^3$ km^3 is returned to the ocean, replenishing the loss of ocean water caused by evaporation.

In his paper, A. Pol'dervaart quotes the data of Keunen that 12 km^3 of insoluble mineral residues are added each year to the ocean in suspension. The distribution of marine sediments in the ocean (according to Keunen) is as follows:

Type of sediments	Area occupied by sediments (km^2 10^6)	Same area of the sea (%)	Average depth
Shelf	30	8	—
Semi-pelagic	63	18	230[illegible]
Pelagic	268	74	440[illegible]

Taking the mean thickness of semi-pelagic and shelf sediments to be 4 km, and that of pelagic sediments to be 600 m (or 300 m of dry matter), A. Pol'dervaart considers these deposits to have accumulated in about 200 million years.

As shown by our calculations given below, either the estimate of the duration of continuous sedimentation was considerably misjudged by A. Pol'dervaart, or all the calculations given on the transfer of sediments to the ocean are only valid for the present-day period, and in past geologic epochs these processes took place many times more slowly. In fact, the total volume of the terrestial part of shelf and semi-pelagic sediments is equal to $300 \cdot 10^6$ km^3.

According to the calculations of A. Pol'dervaart (p. 137), about 0.8 km^3 are deposited annually in the area occupied by pelagic sediments. Consequently, of the 12 km^3 of suspended material that are, according to Keunen, added to the ocean each year, 11.20 km of sediments have to be allotted to the semi-pelagic and shelf regions. Reducing this value to 10 km^3 for simplicity, we find that the total volume of sediments of the semi-pelagic and shelf regions of the ocean, equal to $300 \cdot 10^6$ km^3, could have been deposited within 30 million years at a sedimentation rate of 0.13 mm per year. But the deposition of 10 km^3 each year in the shelf and semi-pelagic regions of the ocean in the course of 200 million years would have led to the accumulation of a mass of sediment with a thickness of more than 20 km in these regions, which contradicts both the geologic and geophysical data. Proceeding from this statement and taking

the time of accumulation of oceanic sediments in the present-day ocean as being equal to about 30 · 10^6 years, we find that 300 m (of solid matter) could have accumulated during this period in the pelagic region at an average sedimentation rate of 0.01 mm per year.

Taking into account the fact that in the quoted calculations allowance was made only for terrigenous material brough in by rivers, although the part played by volcanic material, authigenic minerals and the remains of organisms is undoubtedly considerable, I believe the sedimentation rate of 0.01 mm per year to be nearer the truth than the value of 0.0015 mm adopted by A. Pol'dervaart.

It should also be stated that much recent geophysical data have disclosed a mean thickness of 900 to 1000 m of unconsolidated sediments in abyssal parts of the ocean. It may be assumed that these values correspond to 500 m of solid matter. Proceeding from the sedimentation rate assumed above, which is equal to 0.01 mm a year, the age of the oceans within their present boundaries cannot exceed 50 million years; as we will see later, this is in agreement with certain other data.

SOME GEOLOGIC HYPOTHESES FORMULATED FROM THE RESULTS OF GEOPHYSICAL INVESTIGATIONS

On the basis of accumulated geophysical data, certain geologic hypotheses have come to be formed about the petrographic composition of different layers of the crust, general trends in the development of the crust, and the causes of the different structure (determined from the velocities of elastic waves) of the continental and oceanic crusts.

J. Gilluly, in a paper Geological differences between continental and submarine depressions [2], considers that the difference between the average composition of continental and submarine blocks of the crust is so distinctly corroborated by indirect data that it may be accepted as an indisputable condition. When dealing with the petrographic differences, the author points out that, despite the fact that basic and ultrabasic rocks are widespread in both continental and oceanic depressions, many geologists consider real granite to be representative only of the continents.

On the whole J. Gilluly considers that it is clearly impossible to discriminate between either continental or oceanic rock types. There are oceanic granites and continental oceanites (p. 21), but this, in his opinion, should not contradict the fact that sima predominates in the oceanic crust.

In particular the author refers (p. 23) to the clear geologic indication of the presence of a certain amount of sial in abyssal regions of the southwestern part of the Pacific Ocean; this is indicated by the fact that the area of the sialic blocks of the Fiji, New Caledonia and other islands in the region between Fiji, New Zealand Australia were once much larger, although at the present time a considerable part of this territory lies at depth in the ocean. Much of this area has sunk beneath the ocean level to depths of not less than 4 km, and the problem of this submergence may be compared with the problem of the uplift of the Tibetan Plateau.

When dealing with alterations in the distribution of land and sea, J. Gilluly notes that the geologic chronicle indicates repeated changes of this type, but that it is not quite clear whether these alterations are only peculiar to the epicontinental shelf and depressions or whether they lead to the conversion of oceanic parts of the crust to continental parts and vice versa.

Nevertheless, accepting the data of Arrhenius on the rate of accumulation of pelagic sediments, J. Gilluly acknowledges that the 900 m of clay in abyssal parts of the ocean could have been deposited in 2 billion years. Such a well-known agreement with the conception of the constancy of the oceans within their present boundaries leads the author to certain considerations regarding the sub-crustal mixing of matter, which enable him to draw conclusions on the role of erosion, continental leveling, and the conversion of continental blocks to oceanic blocks.

Bearing in mind the geophysical differences established between the continental and oceanic crust, and connecting these with differences in their petrographic composition, V.A. Magnitskiy considers the continental crust to be sialic and the oceanic crust to be simatic; thereby he develops the hypothesis of the expansion of continents as a result of the migration of silica from the simatic shell during the development of geosynclines. SiO_2 is liberated during the conversion of $MgSiO_2$ to Mg_2SiO_4 under conditions of $t = 1000°$ to $1500°$. The energy necessary for this is obtained, in his opinion, from the decay of radioactive elements contained in the shell. But here, according to V.A. Magnitskiy, arises the first serious difficulty for this hypothesis — why does the process start in separate patches instead of proceeding throughout the whole earth? V.A. Magnitskiy overcomes this difficulty by supposing that there is a lateral variation in the concentration of radioactive elements.

It must be stated that this is not the sole difficulty; besides silica large amounts of alkalie, alumina and water, necessary for the formation of the sial, have to be derived from the simatic shell; it would be difficult to derive these materials from the rock type dunite — peridotite. It is also well known that most of the

radioactive elements occur not in rocks of ultrabasic or basic composition, but rather in those with granitic and alkalic affinities. But the greatest obstacle is the inexplicability of the reason why a similar migration of silica does not take place beneath the oceans, although the equal distribution of the thermal currents must testify to the generally identical amount of radioactive substances dispersed throughout the mantle, and consequently, also throughout the crust.

When explaining the structure of the crust by the hypothesis of the expansion of continents, V. A. Magnitskiy has also to reconcile himself to such data as: 1) the thickness of ocean silt as revealed by geophysical methods is equal to 1 km; 2) the sedimentation rate accepted by him for silt in the ocean depths is equal to 1 cm per 1000 years;[3] 3) the fact that this hypothesis requires an age of at least one billion years for the oceans, instead of an age of 10 million years as obtained from the values considered in the first and second paragraphs. To get out of this difficulty, V. A. Magnitskiy claims, firstly, that part of the sediments are consolidated, and secondly, that in former geologic time the rate of sedimentation was much lower than at present.

Without doubt the problem of the earth's oldest formations has not as yet been adequately studied. To conclude, therefore, that the oldest epochs dominated basic and ultrabasic formations is in my opinion premature. The absolute age determination of the Rhodesian (Africa) and Manitoba (North America) pegmatites at 2700 to $3000 \cdot 10^6$ years indicates only that granitoids of this age intruded metamorphosed formations and that the difference of approximately one billion years in the computed age of the earth (arrens) and the Rhodesian and Manitoba pegmatites may not be considered to be a period during which geologic processes were absent. It still remains to be determined what these processes were and what formed the primary crust of our planet.

V. V. Belousov [4, 5] considers that at the at the present time (evidently in the geologic sense, G. A.) the process is proceeding in the direction of the expansion of oceans at the expense of the continents, i. e., he expresses a viewpoint that is the reverse of the opinions of V. A. Magnitskiy.

Accepting the differences in structure of the crust beneath the continents and oceans, revealed by seismic methods, he mentions the discrepancy included in the notion concerning the association of the granite layer with a continental environment. In particular, in the area of the Indian and Atlantic Oceans, continents were in existence up to recent time, and they scarcely differed in their structure from the modern continents. As V. V. Belousov points out, these continents foundered at approximately the end of the Mesozoic. Since these continents foundered at the end of the Mesozoic, the differences in the thickness of the granite layer between them and the present continents could only have been caused by processes which took place after this period ([4], p. 13) and which led to the indicated origin of anomalies in previously analogous parts of the crust.

Hence, V. V. Belousov arrives at the rather improbable assumption that the granitic layer of the continents is reversible, if only in part. During the submergence experienced by oceanic depressions, the partial disintegration of the granitic layer took place, perhaps by its solution in the underlying basaltic layer ([4], p. 14).

While attempting to explain the still more glaring discrepancy between the geologic data on the youthful age of certain abyssal basins and the oceanic type of crust in these recently foundered terrestial regions, V. V. Tikhomirov [24] arrives at an even more hypothetical assumtion. He cites the following facts. In Abyssal parts of the Bering Sea, according to gravimetric data, the sialic layer has the usual thickness for oceans. In cores lifted from a depth of 3638 m, however, fresh-water diatoms of bentonite of a Quaternary age were discovered, indicating that this part of the sea bed was recently in the littoral zone. From geophysical data, the Sea of Japan is characterized by the usual crustal thickness for oceans. Quoting G. Lindberg, V. V. Tikhomirov points out that a landmass, across which flowed the paleo-Suyfun and paleo-Amur rivers, was still situated in Quaternary time in the region of the present Sea of Japan.

According to V. V. Tikhomirov, it is quite indisputable that the Red Sea, situated in the graben of an ancient platform and most probably originating at the end of the Mesozoic, must have had beneath its bottom a thickness of sialic material equal to that on the adjacent platforms. According to the gravimetric data, however, the thickness of the sialic layer here is also close to the usual figure for oceans. Consequently, V. V. Tikhomirov concludes that if the latest geophysical data are correct, then an explanation has to be found for the disappearance of the sialic layer, which undoubtedly existed in former times both in the Red Sea, the Mediterranean and the Black Sea, as well as in the Sea of Japan, the Bering Sea and certain other areas ([24], p. 10).

[3] We will note that, in his work discussed above, A. Pol'dervaart takes 0.15 cm of solid matter per 1000 years as the most probable rate of silt sedimentation. On the basis of A. Pol'dervaart's data, I estimate a more probable rate of sedimentation to be 0.01 mm a year, which agrees with the figure of V. A. Magnitskiy.

venture to mention that V. V. Tikhomirov [?]oses an extremely artificial explanation [?]his disappearance of the sial in Quaternary [?]ven Tertiary time in platform areas sinking [?]ath the water of the sea. The main idea of [?]uthor is that granites are created principally [?]ugh either metasomatism or magmatic re-[?]ement, the necessary conditions for graniti-[?]n arising only in the zones of uplift. V. V. [?]omirov writes: "Granite is one of the char-[?]cistic components of our planet and origi-[?]d at a definite stage in its geologic develop-[?]: as a result of specific physical and chemi-[?]conditions indigenous to the surface zone" [?]2, my underlining, G. A.).

[?]pparently "definite stage" means the Pre-[?]brian, when, according to the author, the [?]mulation of sial took place as the result of [?]decay of the primary simatic crust of the [?]h, while "specific" physical and chemical [?]litions means residual differentiation, re-[?]ing in the accumulation of sialic material. [?]ough, as a result of all this, the decomposi-[?] prodcuts of the primary crust would have [?]umulated in depressions on the earth's sur-[?] and not in elevated areas; nevertheless, [?]ording to V. V. Tikhomirov, "during the [?]od of accumulation of the sialic crust in [?]es of pre-eminent uplift there arose metaso-[?]ic processes, caused by specific physical [?] chemical conditions (specifically what is [?]explained, G. A.) of parts of the crust. This [?]ulted in complex metamorphism which was [?]summated by granitization.

On the other hand, according to V. V. Tikho-[?]ov, it is sufficient for the sialic layer, with [?]hickness of about 20 km, to have foundered [?]eath the waters of the sea to a depth of about [?]n as this vigorous process of the basification [?]he sialic layer was beginning, which may [?]e eliminated within a short time (the Quater-[?]y period in the Sea of Japan) the granitization [?]ects of former geologic epochs.

Moreover, in no degree whatever does V. V. [?]homirov exclude the assumption of increase [?]hickness of the sialic layer in regions of [?]jor uplift, as a result of the inflow of ma-[?]ial from below. According to V. V. Tikho-[?]rov, the substratum of the crust has on the [?]ole a simatic composition, hence the capacity [?]this substratum to produce the granitization [?]the component rocks during uplift, and their [?]sification during submergence, is clearly [?] tangible.

The opinions of P. N. Kropotkin [6] on dif-[?]entiated and undifferentiated parts of the [?]ust and about questions of petrogenesis were [?]nsidered in my paper of 1953 [2]. The main [?]jection against his generally logical theory [?]petrogenesis is the fact that the composition [?]the substratum, from which he takes out all [?]e remaining types of igneous rocks by means of a somewhat phased differentiation, must partially differ from rocks of the dunite-peridotite type in its radioactive element and alkalie, especially potassium content.

A. P. Vinogradov [10] notes the controversial nature of the causes of changes in the velocity of seismic waves at different depths within the earth. It is not clear whether differences in chemical composition, or changes in the state of matter due to increased pressures and temperatures, operate here. The notion developed by A. P. Vinogradov about the formation of the crust at the expense of the mantle by a process analogous to "zoned fusion" is very interesting. But even allowing for this idea, it is also impossible to explain the differences between the oceanic and continental crust resulting from changes in the velocity of elastic waves, that is if these differences are to be identified with the petrologic peculiarities of the crust.

According to J. Verhoogen [9], the heat flow through continents represents the sum of three components: heat Q_c from radioactive sources in the sialic masses of continents; heat Q_m generated by radioactive sources in the shell which are found above a certain limiting depth that depends on thermal conductivity; the remaining heat Q_i is derived from layers above this limiting depth. Turning to the revealed parity of the thermal flow, J. Verhoogen (p. 401) writes: "There are serious geochemical and petrological arguments against the idea that the shell consists entirely of olivine. Firstly, lavas of the conventional type of eruptive rocks could never have been separated out from a dunitic shell. Secondly, the average composition of the earth in this case would have seriously differed from that of meteorites and from the cosmic abundance of elements, especially in regard to aluminum and the alkaline metals. The dunite or peridotite layer could have been formed during the fractional crystallization or fractional melting of meteoric matter. However, since the average chemical composition of stony meteorites corresponds to 75% peridotite and 25% basalt or granite, a considerable part of the shell should also have to consist of basalt, yet in the shell basalt appears to be absent".

Slikhter indicates (according to the work of J. Verhoogen) the extremely high value of the earth's thermal inertia, due to its large dimensions and the low value of heat conductivity. If heat is transmitted by means of thermal conductivity, then any sudden changes at the earth's surface will not have an effect on the temperature at its center before 200 million years have elapsed.

According to Slikhter, the present flow of heat across the surface is determined essentially by the thermal conditions within a few hundred kilometers (200 to 300) of the surface. In deep zones of the earth there may be, in any case,

large amounts of disseminated radioactive substances, and these will not noticeably alter the measure values of the heat flow. As J. Verhoogen points out, these facts suggest the closeness in average composition of material beneath the continents and oceans, to a depth of several hundred kilometers, participating in the generation of the present thermal current.

In recent works many geophysicists consider as provisional the names "granite", "basalt" and "peridotite" that are attached to crustal layers with differing velocities of elastic waves.

In particular F. Birch, in a paper Physics of the Earth's crust, when differentiating the crust from the underlying substratum on the basis of geophysical data on the Mohorovicic discontinuity, points out that "it is still not known to what extent the chemical discontinuity corresponds to the discontinuity of physical properties" (p. 115). He goes on to mention that there are very few data for sedimentary and metamorphic rocks, although the crust, in all probability, largely consists of these types, and the velocities, in dolomite for example, differ very little from the velocities in gabbro.

It is important to mention the following statement of F. Birch (p. 117): "According to a new, more reliable point of view, the earth's crust is a mosaic of a diverse family of intrusions, metamorphosed sediments, volcanic rocks and even, in places to a depth of 10 km and more, of unmetamorphosed sediments. All these rocks are pierced by faults and are split into blocks of different sizes and forms. One of the reasons for the apparent homogeneity of seismic velocities in the crust, despite the heterogeneity of its material, may quite well be the comparatively narrow range of variation in the velocities for a very wide series of igneous rocks—syenite to diorite".

This preceding review shows that the attempts made to explain different geophysical characteristics of the crustal structure in various areas by peculiarities in the composition and evolution of the rocks constituting the crust are inconsistent, and can not explain many geologic and geophysical facts.

There are two groups of facts: one — geophysical data on the differing velocities of elastic waves in various shells of the earth; two — geologic facts about the youthful age (Cenozoic or even Quaternary) of the subsidence of the geophysical character of these areas to one similar to that of the present ocean bottom, i. e., as if the sial had disappeared.

At the same time, it is known to us that many oceanic islands, situated in abyssal parts of the Pacific, Atlantic and Indian Oceans, are composed of typical sialic formations, including crystalline schist and granite.

The conclusions based on these two groups of facts are inconsistent, and this, apparently, indicates that either there are still insufficient facts or the geologic interpretation of the geophysical data is on the whole incorrect.

SOME GEOLOGIC FACTS ESSENTIAL FOR ASSESSING THE STRUCTURE OF THE EARTH'S CRUST

To solve the problem of the structure of the earth's crust in oceanic and continental regions the question of the age (time of existence) of the oceans within their present boundaries on the earth's surface is most essential, as has been stated above.

The two different points of view about the growth of continents at the expense of oceans or, on the contrary, about the expansion of oceans and their absorption of the continents are inconsistent and one certainly cannot claim them to be indisputable. In addition there is a mass of geologic facts indicating serious changes in the depths of oceans within their present boundaries.

Kh. M. Saidova [22], while studying benthonic foraminifera in the northwestern part of the Pacific Ocean and their abundance in both recent and deeper sediments, comes to the conclusion that the bottom of this part of the ocean was submerged in the Holocene to 1000 or 2000 m.

M. Krishnan [17, 39] considers that the Indian Ocean, starting from the Permian, stretched from East Africa to Australia. Madagascar, India, Africa and Australia were split off in the Triassic and Early Jurassic. The dismemberment of Gondwanaland was completed by the Early Cretaceous. He also pays attention to the significance of Tertiary time, when grandiose eruptions of lava occurred — the Deccan traps, and the development of the Himalayan from Persia and Syria to Indonesia.

H. Ladd, E. Ingerson and others [40, 41] have published an account of the results of drilling in the Eniwetok atoll (Marshall Islands). According to their data, the main atoll is a basalt volcano, rising 2 miles above the ocean bottom. Passing through calcareous formations at the surface of the atoll, Borehole E-1 struck olivine basalt at a depth of 4208 to 4222 ft. The section above the basalt consisted of the following deposits: a) Eocene limestone with a characteristic fauna and a thickness of 1370 ft; b) Miocene beds with a thickness of 2200 ft; c) Pliocene and post-Pliocene beds with a thickness of 600 ft. The upper 400 ft. are considered to be Quaternary and the very uppermost 100 ft. are assigned to the Recent.

The cited data show that the island was raised above water during the Oligocene (the Oligocene

issing from the section), and, starting from Miocene, was submerged again to 2800 ft. some apparently positive movements of a porary nature, which are indicated by the elopment of coral structures. The variable re of the upper part of the revealed basalt ifies rather to the transgressive deposition ocene limestones, the olivine basalt there- representing the base of the island. Eniwe- atoll is pre-Eocene and probably is close to Deccan traps in age.

. MacDonald [43], in a work on the Hawaiian ographic province, distinguishes in a num- of islands in the Hawaiian Archipelago, on basis of a geologic survey and a petrographic ly, an ancient Tertiary (?) group of igneous ks and volcanic material. After a consider- e interval of erosion this older formation covered by the younger Pleistocene products volcanoes which continued until recent time e-historic and historic activity of the vol- oes of the Hawaiian Islands).

The old series on the islands of Kauai, Oahu others is represented by olivine basalt, rite and andesite. They are at times dis- ted by gabbro stocks and contain dunite xeno- s. Later volcanic formations are nepheline alt, melilite-nepheline basalt, antarctite, heline basanite and also individual flows and ses of trachyte.

In historic times olivine basalt predominated ongst the outflows from the volcano of Kilaue. e outflows of Mauna Loa volcano during this me period are characterized by predominantly persthene-bearing basalt and to a lesser de- ee olivine basalt and picrite.

In Oceania, a petrographic survey by P. arshall devoted to the islands of the Pacific ean, facts are cited on the development of ialic" rocks, such as metamorphic schist and en granite, on many islands — the Carolines, e Marquesas and the Solomons.

In the paper of J. Gilluly [12] the data are so cited on the presence of sialic rocks on pically oceanic islands. In particular, for ample, granite and gneiss are found on the eychelle Islands (Indian Ocean) and granite d schist on the Fiji-Tonga islands. Rhyolite d granitic rocks are also noted by him on the lands of Ascension, the Falklands and Cape reen. A number of facts about the presence of anitoid rocks on oceanic islands are given in y paper of 1953 [2].

One of the arguments of those who adhere to e indigenously different history (from the me of formation of the primary crust of the arth) and structure of the crust in the region f continents and the bottom of oceans was the pparently specific character of volcanism on ceanic islands. The so-called "oceanites" were distinguished on these grounds. On many occasions during the comparison of the petrographic type of volcanic rocks from oceanic islands and continents, R. Daly, G. MacDonald and others did not find much difference in their chemistry. For my part I will note that a specific type of magmatism developed between the end of the Mesozoic and the Cenozoic. In many places around the earth both in oceanic and continental regions, sub-alkalic and alkalic complexes of basic rocks — basaltoids and associated nepheline and feldspathoidal rocks — were formed.

It is interesting also to note the enormous areas of trap deposits, with a thickness of up to 3 km, in India, South Africa and the Siberian platform, as well as the unusual formation of ultrabasic and alkalic rocks in the basin of the Khatanga River (Siberian platform). This latter formation, studied by Ye. L. Butakova and L. S. Yegorov (personal communication) includes basalt, nepheline basalt, melilite basalt, picrite porphyry (meymechite), trachyte, andesite and numerous other varieties of alkalic and subalkalic rocks. This association, including meymechite (picrite porphyry), is completely analogour to that (oceanite) which is known to be characteristic of the volcanism of oceanic islands. A Triassic age is provisionally assigned to such a typical oceanic association in the north of the Siberian platform. It lies on a basement of Permian, Ordovician and Precambrian rocks. Analogous types of extrusive rocks are known in Armenia, although this area now clearly belongs to the continent.

All this shows that variously aged and highly diverse petrographic associations of igneous rocks are developed within the continents. Unfortunately, however, these have at present been insufficiently studied to determine the precise abundance of the series which they form in time and space.

In the diagrams (Figures 1, 2) the figurative points of typical "oceanic" and certain "continental", and magmatic rocks are shown, as well as the average types of extrusions in separate volcanic areas. It is evident from these illustrations that the volcanism of oceanic islands is not of an especially specific character.

As has been shown above, the accumulated layers of unconsolidated and weakly consolidated sediments probably correspond to a time of about 60 million years. During the Cenozoic, we know that the formation of the highest mountain ranges in the region of the Tethys took place, and that in individual parts of the basin of the Pacific Ocean sea level was at least 1000 m lower than at present.

All these indirect data cannot, of course, solve the question of the age of the present oceans (within their present confines) until positive facts are obtained on the geologic

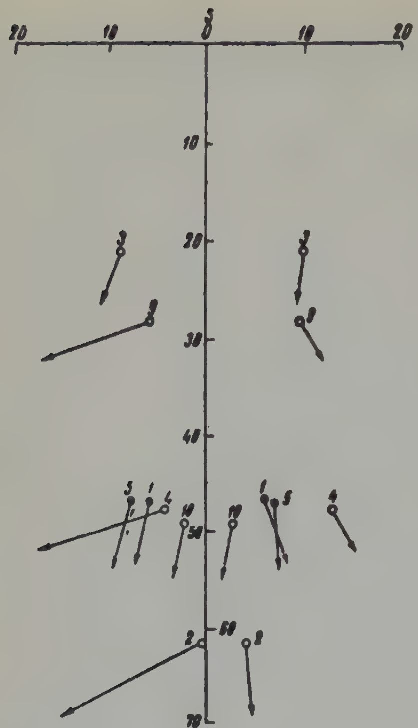

FIGURE 1. Average composition of basic extrusives from some oceanic and continental regions.

1 - Hawaiian picrite (average of five analyses); 2 - picrite meymechite from the Khatanga River (average of three analyses); 3 - basalt from the western Caucasus (average of three analyses); 4 - melilite basalt from the Khatanga River; 5 - oceanite from Reunion Island and Piton de la Furnez; 9 - potash basalt from Adzhariya; 10 - picrite diabase porphyry from Armenia. Light circles with arrows - continental, dark circles - oceanic.

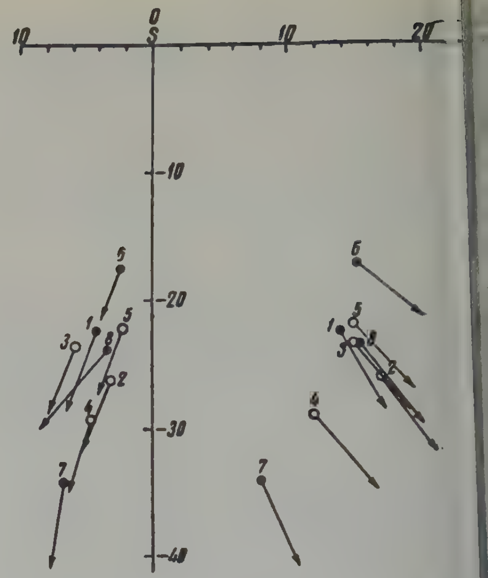

FIGURE 2. Average composition of volcanic rocks from some continental and oceanic regions.

1 - the Azores (average of twenty analyses); 2 - Kaisershtule (average of nine analyses; 3 - Odenvald - Spessartite (average of ten analyses) 4 - Hessian mining region (mean of fourteen analyses); 5 - volcanoes of Auvergne (Puy de Dôme) (average of eight analyses); 6 - island of St. Helena (average of eleven analyses); 7 - Kilauea (average of twenty analyses); 8 - Haleakal (average of twelve analyses). Light circles with arrows - continental, dark circles - oceanic.

section of the rocks forming the ocean bottom to at least 1 to 1.5 km in abyssal parts of the ocean. But history, being the essence of geology as a science, enables us to be confident, on the basis of the authentic facts of geologic knowledge of the present continents, that the periodicity of geologic processes on the earth has been the leitmotif of its development from the early Precambrian up to the present period.

As has been repeatedly noted, however, this periodicity is not a simple recurrence leading to uniformity, but is characterised by new peculiarities additionally indigenous to each stage and which correspond to the over-all process of the earth's development as a planet.

Two-thirds of the earth's surface is now hidden by water, but this does not mean that the patterns of development of the crust, revealed for the present continents and shown in historic perspective by the change of marine and continental environments, and by the replacement of platform conditions by mobile developments of a geosynclinal type with the accompanying phenomena of orogeny, magmatism, erosion and sedimentation, cannot also be applied to terrestial regions now concealed by water.

As regards the known quiescent existence of considerable terrestial areas (sheilds) constituting the cores of the present continents, we may only infer this for a relatively short segment of geologic time, about 500 million years (Paleozoic, Mesozoic, Cenozoic); the preceding Precambrian, even in areas of continental platform illustrates the high activity of the geologic processes of that period. Amongst the deeply metamorphosed strata of the Precambrian many formations of sedimentary rocks are quite probabl present, having been laid down in the oceanic basins of Precambrian time.

Thus, apart from indirect data on the differe

ocities of longitudinal waves on the continents 1 beneath the oceans, we have no facts whater for recognizing the constancy of the oceans 1 for working out any hypotheses about the ferent history of the sial in various parts of crust. On the contrary, the distribution of heat current in oceanic and continental rens rather testifies to the closeness of the erage composition of matter in these areas a depth of about 200 or 300 km.

Before turning to the examination of concrete ophysical data of recent times, I will dwell some physical bases for the parallelism beeen the velocities of elastic waves and the trographic composition of the rocks in which ey travel.

On the basis of the study of the elastic propties of rocks, it is usually considered that velocity of longitudinal and elastic waves granite is equal to or somewhat more than 5 km[sec, in basalt — from 6 to 7.5 km/sec d in ultrabasic rocks — 8.1 to 8.3 km/sec.

But, according to the data of D. Hughes and Cross, who determined experimentally the locity of elastic waves in dunite at P = 70 rs and t = 24.5, it equals 8.603 km/sec, hich disagrees with data for the dunitic comsition of the upper part of the mantle. During periments on specimens that were verified in e field, the velocity of longitudinal waves in anite ranged from 4.9 to 5.6 km/sec; with creasing pressure the velocity increased to 4 (D. Hughes), by 16 to 18% (Yu. V. Riznichko).

According to E. Hamilton's data in his paper ickness and consolidation of deep-sea sediments, it is shown experimentally that by the nsolidation and lithification of bottom calreous muds the velocity of propagation of astic waves in these consolidated rocks is creased to 5.5 km/sec, i.e., the velocity ecomes "granitic".

The data on the velocities of transverse waves peared in a reference book published by F. irch et al. Part of these data are quoted in able 1, from which it is evident that the velocy of transverse waves in the Quincy and Rockort granites increases considerably at high ressures. The experimental measurement as also made of the velocity of longitudinal nd lateral waves in the ground in the Quincy nd Rockport granites, over a small part of heir profile in depth.

The velocity of lateral waves for basic and ltrabasic rocks under similar conditions shows much lower increase.

Utilizing the experimental data of D. Hughes nd J. Cross, B. Gutenberg in an article from he collection Crust of the Earth (Figure 3) gives the values for the velocities of longitudinal waves in dunite, granite and limestone under increased pressures and temperatures. From this diagram (Figure 3) it is evident that the velocity in dunite is increased from 8.6 to 8.8 km/sec.

In a paper on the velocities of elastic waves in rocks under high temperatures and pressures, D. Hughes and J. Cross cite the following results of their experimental research (Table 2). In this table data are presented for dunite having a density of 3.160 and consisting of 90% olivine and 10% augite. According to these data, the velocity of elastic waves (V_D) at P = 70 bars and t = 24.5° is 8.603 km/sec. With a rise in pressure up to P = 690 bars (t = 24.5°) V = 8.820 km/sec, i.e., the velocity is increased by 2.5%, while at a pressure of 2.415 bars it increases to 8.926 km/sec or by 3.8%. Proceeding from these data of D. Hughes and J. Cross, one may believe that "dunite", if it forms the top of the mantle beneath the ocean bottom, must possess a velocity V_D on the order of 8.7 to 8.8 km/sec.

From the same work, the data for granite of Barifield, Ontario (Table 3, show an increase of V_D from 5.640 km/sec at P = 20 bars and t = 28° to 6.215 km/sec at P = 500 bars and to 6.384 km/sec at P = 2000 bars. At t = 100° this granite has V_D = 6.243 km/sec when P = 500 bars and V_D = 6.372 km/sec when P = 2000 bars. Thus, as the pressure rises to the probable value for ocean bottom conditions, the velocity of elastic waves may be increased by 10 to 15%.

According to the data of Yu. V. Riznichenko, the velocity of longitudinal waves in granite when the pressure rises to 1000 kg is increased by 16 to 18%.

The importance of the load from the overlying rocks on the velocity of propagation of longitudinal waves in the underlying rocks was experimentally verified by A. Laughton [42] for Cretaceous strata in Yorkshire, where V = 3.00 km/sec for the upper layers and 5.00 km/sec for specimens from below 400 m. In precisely the same way, V.B. Sologub et al have obtained, at the Academy of Sciences of the Ukrainian S.S.R., some interesting data on changes in the velocity of longitudinal waves in sandstone and certain other rocks in relation to the load and degree of water saturation.

When comparing experimental data about the velocities of elastic waves at high pressures with data for the velocities of elastic waves in the continental crust, the following circumstances arrest one's attention.

According to Kh. Teytl and M. T'yuv [24a], the average velocity grows only slightly with depth within the first two-thirds of the crust (about 20 km), i.e., it rises from a velocity of ~ 6 km/sec to one of 6.4 km/sec. In the

Table 1

Velocity of propagation of transverse waves in relation to pressure at t = 30°
(according to F. Birch and J. Turner, 1942)

Rock	P=1		P=500 kg		P=4000 kg		Velocity of f long. wave to 1800 m at Rockport and to 1100 at Quincy $V_p : V_s$
	km/sec	km/sec	% inc.	km/sec	where P=1%	where P=500%	
Rockport granite, mean	2.56	3.42	—	3.59	—	—	5.14; 2.70
Quincy granite, mean	2.61	3.45	—	3.61	—	—	4.96; 2.48
Mean for granite	2.59	3.44	32	3.60	39	4.6	
Granodiorite	3.14	3.45	10	3.58	14	4.0	
Sudbury norite	3.15	3.61	14.5	3.70	17	2.5	6.22: 3.49 Depth 350—3000)
Diabase (mean of different specimens)	3.58	3.76	5	3.85	7.5	2.4	
Gabbro (mean)	3.32	3.75	3.3	3.85	13.0	2.6	
Dunite ('')	4.12	4.44	7.7	4.57	10.9	2.9	

Table 2

Determination of the velocities of elastic waves in dunite according
to D. Hughes and J. Cross [39]

T°	24,5		100		200		300		24	
Bars	v_D	v_R	v_D	v_R	v_D	v_R	v_D	v_R	v_D	v_R
70	8.603	4.185	8.367	4.224	—	—	—	—	8.725	4.390
138	8.694	4.244	8.434	4,289	8.155	4.133	7.701	4.016	8.788	4,425
345	8.746	4.406	8.635	4.393	8.448	4.286	8.033	—	8.874	4.456
690	8.820	4.435	8.748	8,434	8.691	4.442	8.404	4.320	8.907	4,467
1.035	8.873	4.456	8,791	4,439	8.710	4.512	8.572	4.368	8.928	4,490
1,725	8.905	4.515	8,821	4,470	8.783	4.467	8.652	4.444	8.973	4.510
2,415	8.926	4.545	8.884	4,480	8.793	4.440	8.703	4.397	8.983	4,526
4,140	8.956	4.533	8.892	4,426	8.886	4.492	8.784	4.433	9.062	4.549
5.170	8.977	4.529	8,987	4,559	8,895	4.514	8.792	4.459	9,096	4.539

same gradual way the velocity increases from 6.5 to 7.05 km/sec in the underlying, so-called basaltic layer having a thickness of about 10 km.

This type of variation in the velocities of elastic waves testifies to the gradual change in the physical state of matter, rather than to abrupt interchanges of thick layers of crystalline rocks with rocks of different composition and density. It is thereby pertinent to recall the "realistic notion" of F. Birch, quoted above, about the structure of the upper part of the crust as a mosaic of rocks of a variable composition. From these positions the gradual and slow increase in the mean velocities to a considerable depth is understandable.

According to the experimental data of D. Hughes and J. Cross, and also of Yu. V. Riznichenko, the velocity of longitudinal waves in granite rises by 16 to 18% (Yu. V. Riznichenko) and to 6.3 to 6.4 km/sec (D. Hughes) when the pressure is 1000 to 1500 kg/cm^2.

If it is assumed that the pressure of the load from the overlying rocks is identical to the wei of a column of heavy liquid of a corresponding density [2, 7], then pressures on the order of 1000 to 1500 kg/cm^2 must be accepted for the first 6 km of depth in the continental crust; with increasing depth and pressure, right down to the Mohorovicic surface, the growth in the velocity of elastic waves proceeds much more slowly. What role is played by changes in the density, the elastic properties of rocks (e.g., Young's modulus), the cohesive force in crysta line bodies and so forth, in combination with thermal effects, has not as yet been ascertaine to a sufficient extent.

In particular, F. Birch [7], when examining the question of the range of stresses within the

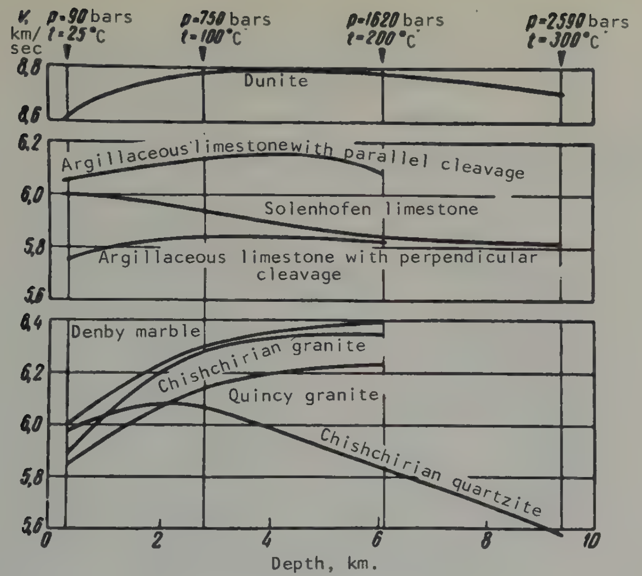

FIGURE 3. Variation in velocities of longitudinal waves in specimens in relation to pressure and temperature, after B. Gutenberg [13, 36].

st, writes: "It is considered that all esses result in a simple pressure, as if the st were a simple heavy liquid, but this ıld be too crude a simplification" (p. 27). h a pressure = Pgh is easily calculated. ery stress may be resolved into a mean ssure, having the character of hydrostatic ssure, and into a system of tangential esses for which the mean pressure equals o.

Assuming that the mean pressure is equal to one-third of the sum of the main stresses and that it must lie within the range Pgh ± 4/3 S (S being themaximum tangential stress), F. Birch gives the approximate values of the mean pressure at different depths. In particular, for a depth of 20 km within the crust, the mean pressure in bars has a maximum of 9500 and a minimum of 1500. This implies granitic rocks, for which he takes S as being equal to 3000 bars.

Table 3

Determination of velocities of elastic waves in granite according to D. Hughes and J. Cross [39] (granite from Barifield, Ontario)

T°	28		100		200		28		300		28	
Bars	v_D	v_R	v_D	v_R	v_D	v_R	v_D	v_R	v_D	v_R	v_D	v_R
20	5.640	2.866	—	—	—	—	—	—	—	—	—	—
50	5,824	2,930	5,966	2,996	5.062	2.768	5.774	2.936	—	—	5.753	2.784
100	5.875	3,961	6,011	3,045	5.199	2,865	5,850	2.977	—	—	5,749	2,797
250	0,080	3,046	6.130	3.107	5.520	2.980	0,066	3.061	4.448	—	5.815	2.785
500	6.215	3.109	6.243	3.159	5.961	3.083	6.235	3,129	4.838	—	5.831	2.803
750	6,288	3.163	6.282	3.195	6.138	3.160	6.302	3.172	5.101	—	5,865	2,793
1000	6.336	3.155	6.325	3.197	6,237	3.166	6.347	3,170	5.223	—	5.898	2.813
1500	6,370	3.169	6.354	3.193	6.304	3.181	6.380	3,174	5.401	—	5.941	2,800
2000	6.384	3.209	6.372	3.202	6.317	3.193	6.415	3.195	5.526	—	5,997	2.814
2500	6.403	3.233	6.391	3.211	6.336	3.181	6.423	3.232	5.618	—	6.022	2,825
3000	6,412	3.215	6.405	3.226	6.354	3.186	6.438	3.244	5.676	—	6.053	2,850
4000	6,429	3.231	6.428	3.243	6.387	3,196	6.481	3.256	5.706	—	6,105	2,869
5000	5.447	3.228	6.446	3.224	6.420	3.224	6.505	3.210	5.874	—	6.191	2,910

Table 4

Densities of some rocks (collection of G. D. Afanas'yev)[1]

Site of sample collection	Rock	Volumetric weight, g	Specific weight	Porosity (%)
Ceylon	Precambrian gneiss	2.773	2.782	0.33
Ceylon	Charnockite	2.972	2.987	0.50
Ceylon	Charnockite	2.913	2.930	0.59
Ceylon	Charnockite	2.907	2.919	0.42
India	Charnockite	2.802	2.803	0.36
India	Granite (Rapakivi)	2.696	2.717	0.77
India	Trap (Bombay)	2.821	2.834	0.46
Caucasus	Granite (Dar'yal)	2.675	2.717	1.55
Caucasus	Phyllite (Dar'yal)	2.700	2.796	3.44
Caucasus	Plagioaplite (Laba)	2.712	2.723	0.41
Mean values	Granite		2.637	
from tables	Granodiorite		2.716	
of F. Birch	Gabbro		2.976	
	Peridotite		3.234	

[1]Determinations by Ye. A. Sanina (Laboratory of the Physical Properties of Rocks, Institute of the Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry, Academy of Sciences, U.S.S.R.).

Turning to the oceanic crust, it is necessary to point out that R. Raitt and G. Shor [47] consider from recent data that the study of seismic waves enables a four-layer model of the crust (of the Pacific Ocean) to be constructed, with velocities for the individual layers of 2, 5, 6.8 and 8.2 km/sec. This model is applicable, apparently, to abyssal parts of the ocean; the crust approximates the continental type in island regions.

Unfortunately, I do not know of any value for longitudinal waves in basalt or gabbro at different pressures that has been obtained experimentally. But pressures on the order of 1000 to 1500 kg/cm^2, resulting from the load of the overlying medium and under which the velocity in granite and marble reaches 6.4 km/sec, are created in the rocks constituting the ocean bottom, apparently within the upper third of the so-called "basaltic" layer. This value will depend on the weight of: 1) the two-kilometer layer of "basalt" with a density of 2.8 to 2.9; 2) the series of rocks in which the velocity of longitudinal waves is equal to 5 km/sec, with a thickness of about 2 km; 3) the layer of unconsolidated sediments with a thickness of about 1 km; 4) the column of ocean water, 5 to 6 km deep, creating a constant pressure on the order of 500 to 600 kg/cm^2 on the underlying solid rocks. In the calculation of the stresses originating in rocks of the bottom region, there are no complications connected with their elastic properties and the cohesive force in the compressed body. In this respect the oceanic crust differs radically from the continental crust. But if one takes into account thereby the fact that such conditions have operated on the ocean bottom for tens of millions of years, even thro[ugh] the densities of many metamorphic rocks from Hindustan and Ceylon (see Table 4), determine[d] by Ye. A. Sanina (Institute of the Geology of Or[e] Deposits, Petrology, Mineralogy and Geochem-istry of the Academy of Sciences, U.S.S.R.) are near to or even exceed the density of basal[t] rocks, then it is natural to raise the question as to whether it is correct to identify the layer[s] of the "oceanic" crust proper with basalt.

Masses of basalt, up to 3 km thick, are possible amdist the crustal rocks of the bottom of the Pacific Ocean, similar to the Deccan traps. The probability is not excluded of the presence in the same place, amidst the crustal rocks, o[f] thick masses of metamorphic rocks resembling charnockite, etc. At the same time, the mean velocity of longitudinal waves of 6.8 km/sec (R. Raitt's model of the bottom of the Pacific) for the "basalt" layer differs less from the velocity of 6.4 km/sec in granite (at a pressure of 1000 to 1500 kg/cm^2) than the density of gran-ite differs from the density of basalt.

Taking into consideration the existing relati[on]ship between density, pressure and the velociti[es] of elastic waves, you will involuntarily ask you[r]slef whether it is impossible to suggest that near-by stresses are brought into being at a different depth: on the order of 20 km in the "layers" of the continental crust and within the so-called basalt layer in the ocean crust!

Such a question, coupled with the conception of rigidity, cohesive forces in a crystalline bo[dy], rupture, flow, etc., is still illuminated both ex-perimentally and theoretically; but precise dat[a]

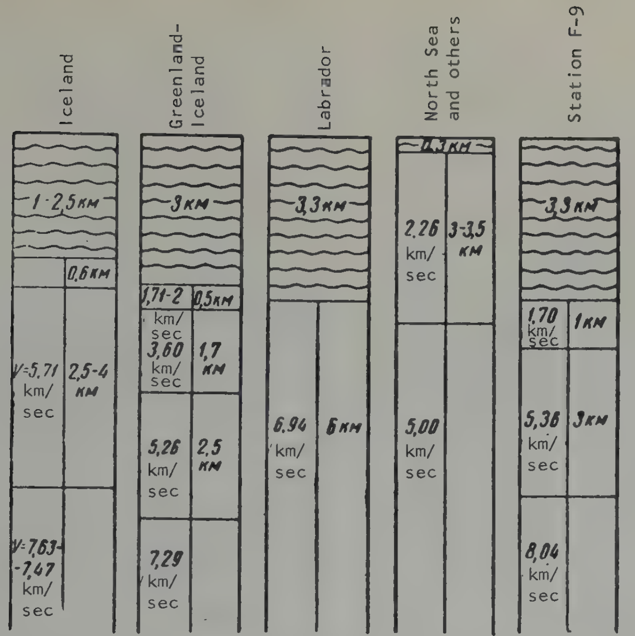

FIGURE 4. Sections of the bottom of the Atlantic Ocean, after J. Ewing and M. Ewing [34].

ɜupport of these conceptions are exceedingly ɔortant for the understanding of changes in physical state of matter in the crust with ich the different values for the velocities of ɔpagation of elastic waves are also connected.

OME SPECIFIC SECTIONS OF THE CRUST FROM THE SEISMIC DATA OF 1958-1959

In 1959 J. Ewing and M. Ewing [34] published rk giving an account of the results of deep smic soundings on the bottom of the Atlantic ean, the Mediterranean Sea and the Norwegian a. A paper by A.A. Gagel'yants, Ye.I. Gal'-rin, I.P. Kosminskaya and R.M. Krokshina me out in 1959 on the structure of the crust the central part of the Caspian Sea from the ta of deep seismic soundings. For our prob-n — to ascertain the accuracy of the petro-aphic interpretation of geophysical data — it interesting to consider the particular sections rough the crust given by these authors.

Sections, after J. Ewing and M. Ewing [34], e presented in Figures 4, 5 and 6 for particu-r parts of the bottom of the seas studied by em. But the sections are grouped by me for ations which have a similar crustal structure d which are connected by the common nature their oceanographic and, in all probability, ologic environments. In all, the authors rried out seismic measurements at 50 stations the Atlantic Ocean. In general, the sections show the monotypical character of particular sections of the bottom of the Atlantic Ocean. The layer with a velocity of longitudinal waves above 8.0 km/sec is only discernable in separate areas, outlined by a dotted line on the map copied from the work of J. Ewing and M. Ewing (Figure 7).

At the bottom of the North Sea and other seas with a depth of water of some hundreds of meters, the following layers of the crust are distinguished (Stations E-12, E-13, E-14): a feebly consolidated layer, 3 to 3.5 km thick, with V = to 2.26 km/sec, underlain by a layer with V = 4.96 (approx. 5) km/sec.

In the Mediterranean Sea, three stations with a depth of water of 2.5 to 3.5 km showed the presence beneath a layer of loose sediments (V = 1.71 km/sec) of a layer in which V = 4.20 to 5.7 km/sec. For Station D-11, a layer with V = 6.50 km/sec was revealed at a depth of 8 km (from sea level). In the section for Station D-7, between Spain and Africa, a layer with V = 6.08 km/sec was revealed beneath a layer of unconsolidated sediment (V = 1.71 km/sec).

The data of R. Raitt et al [20] are similarly of great interest. They investigated the deep-water trench of Tonga and found its structure to be as follows. At a depth of about 10 km beneath ocean level, a layer of unconsolidated sediment with a thickness of less than 0.2 km

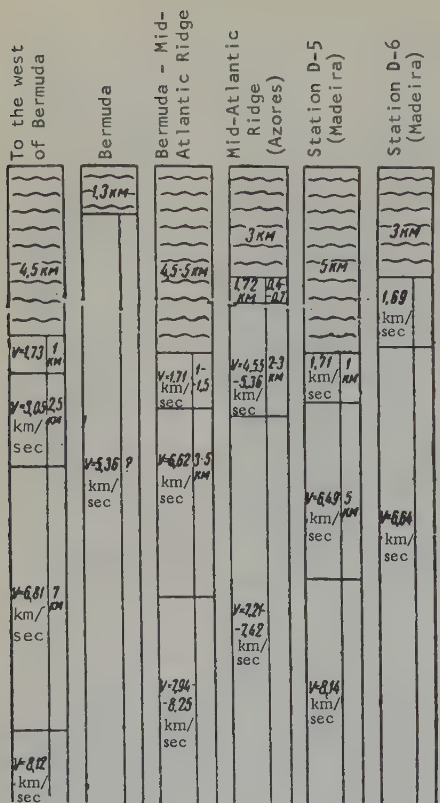

FIGURE 5. Sections of the bottom of the Atlantic Ocean, after J. Ewing and M. Ewing [34].

occurs at the bottom of the trench; then comes a layer with V = 5.3 km/sec and a thickness of 3.0 km. Still deeper a layer having a thickness of 8.2 km and V = 6.5 km/sec occurs; the Mohorovicic discontinuity was revealed below this, the velocity in the underlying rocks being 8.2 km/sec.

In another work, R.W. Raitt et al [45] present a section for Bikini atoll in the Pacific Ocean. Here, straight from the surface (ocean level), is a layer with V = 2.45 km/sec (coral reefs?) and a thickness of 0.5 km. Still deeper comes a layer with V = 4.13 km/sec and a thickness of 2 km. This is underlain by a layer in which V = 5.54 km/sec. I have quoted above the opinion of these authors about the fact that the Mohorovicic discontinuity is found at a depth of 18 km beneath these atolls. It is interesting to note that a section for the prominence of Silvania is given in the paper of R. Raitt. In this section, no more than 20 km distant from Bikini atoll, the crustal structure is quite different. At a depth of 2000 km beneath ocean level an upper layer (V = 2.40 km/sec) was discovered here with a thickness of 0.5 km; then comes a layer with an indeterminate value for the velocity of longitudinal waves. Still deeper begins a layer (basalt? G.A.) with V = 6.15 km/sec.

At the same time, the work of H. Ladd et al [40], devoted to an account of the results from a deep borehole on Eniwetok atoll, which also belongs to the same group of coral islands, indicates that a layer of coralline and calcareous formations was discovered here with a thickness of 1.5 km, and that the borehole penetrated about 15 m into the basalt.

When comparing these data for such closely situated atolls, especially while bearing in mind the results from the borehole of the Eniwetok atoll, it is impossible not to remark how extremely difficult it is to pass judgment on the petrographic composition of the crust in the Bikini area on the basis of differences in the velocities of elastic waves. One may only speak with confidence about the fact that the upper layer (with a general thickness of 4 km) with V = from 2.45 to 4.13 km/sec is composed rather of sedimentary (carbonate) rocks.

The results of deep seismic soundings in the Caspian Sea enable the authors of the paper [1] to arrive at the following conclusions about the structure of the crust in this area. In the platform region (northeast of the Baku-Krasnovodsk isthmus) the crust consists of: a) a sedimentary layer, 2 to 3 km thick, with V = 3 km/sec; b) a granitic layer, 10 to 15 km thick, with velocities for V of about 6 km/sec; c) a basalt layer with V = 6.3 to 6.8 km/sec and a thickness of 20 to 25 km. The total thickness of the crust here is 30 to 35 km.

No granite layer is distinguished by seismic data in the region of the depression (South Caspian), and the crust consists essentially of two layers of: a) a thick sedimentary stratum (more than 20 km) with a low mean velocity of 3.5 to 4.0 km/sec for longitudinal waves; b) a basalt layer with a velocity of 6.6 km/sec for longitudinal waves. The thickness of the crust here is 40 to 45 km (typically continental, G.A.).

To draw conclusions on the basis of these data about the disappearance of the granitic layer (i.e., the rocks for which V is about 6 km/sec) in the southern part of the Caspian is premature till such time as the significance of the load of the overlying rocks for the increase in velocity of the longitudinal waves has been evaluated. The granite layer of the platform (V = 6 km/sec) is covered by a 2 to 3 km stratum of sedimentary rocks, and the "basalt" layer (V = 6.6 km/sec) of the southern Caspian is covered by a mass of rocks ten times as thick, with the constant pressure of a 1000 m column of water over them.

Turning to all the cited sections of the crust in different areas of the bottom of seas and oceans, you will involuntarily ask yourself the

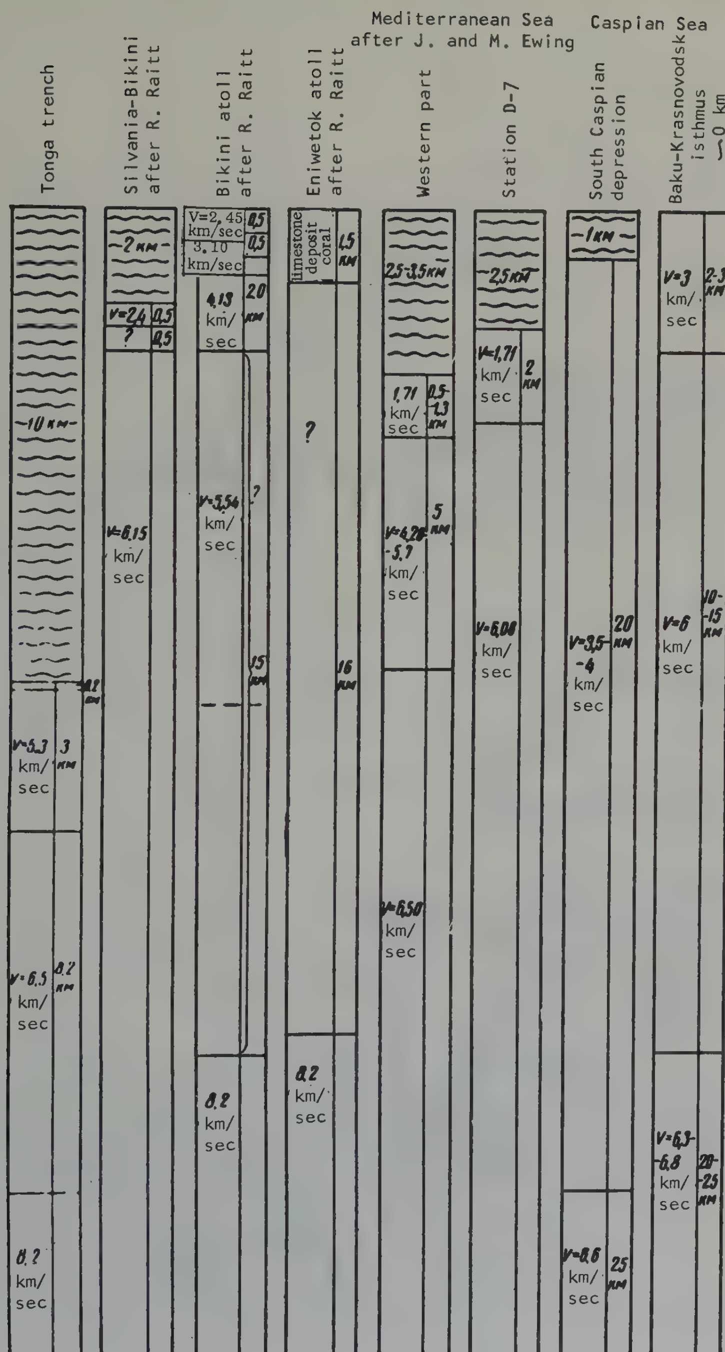

FIGURE 6. Bottom sections from seismic data for the Pacific Ocean (R. Raitt et al.), the Mediterranean Sea (J. Ewing and M. Ewing) and the Caspian Sea (Ye.I. Gal'perin et al.).

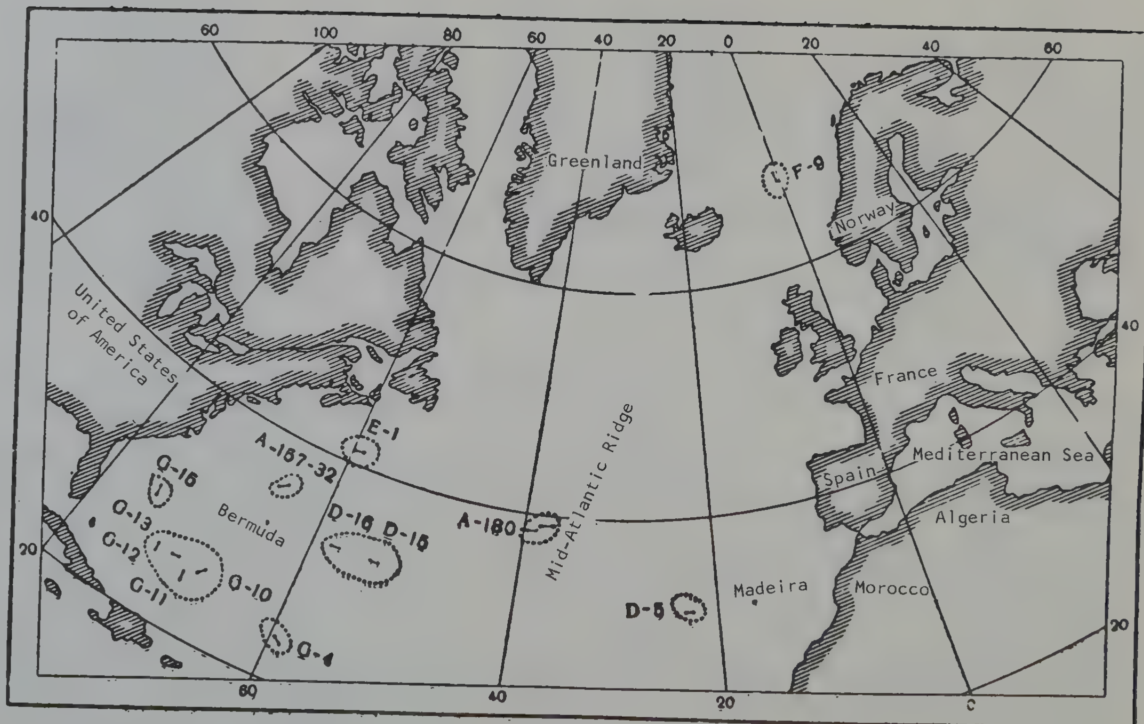

FIGURE 7. Distribution of bottom areas in the Atlantic Ocean wherein the Mohorovicic discontinuity ($V \geqslant 8$ km/sec) was revealed. From the work of J. Ewing and M. Ewing [34]. Ovals enclosed by a dotted line contain the stations at which seismic observations showed the presence of a layer with $V \geqslant 8.0$ km/sec in the bottom section.

question whether it is possible to coordinate all the diverse (in respect to characteristic velocity of longitudinal waves) layers with differences in petrographic composition according to the scheme "continental" and "oceanic" crust.

When comparing the cited specific sections of oceans and seas with experimental data, it is possible to come to the conclusion that nowhere beneath the ocean do the detected velocities of elastic waves, which attain 8.2 km/sec, correspond to velocities measured experimentally for ultrabasic rocks occurring under a pressure of 690 or 1000 bars, and that such pressure conditions, especially in the course of at least tens of millions of years, are realized in the abyssal parts of oceans. In the Atlantic Ocean, the areas from which the Mohorovicic surface (V = 8.1 ± 0.1 km/sec) is removed are distributed unevenly without any sort of pattern, being principally associated with depressions in the submarine topography.

In the Tonga trench, the velocity of 8.2 km/sec is characteristic of the layer underlying the stratum of dense rocks (V = 3.3 and 6.5 km/sec), having a thickness of 11 km and occurring under a 10-kilometer column of ocean water. Incidentally, the principle of the correlation of the depth of the mantle's occurrence and the depth of the ocean is not confirmed for this trench. Proceeding from this principle in the Tonga trench, the so-called "basaltic" layer should be absent, and the "mantle" should occur directly beneath the ocean sediments.

In the light of the stated data, the velocity of 8.0 ± 0.1 km/sec, detected in the very upper part of the so-called mantle in oceanic regions, may correspond to a change in the physical state of matter within the crust. The mass development of basalt extrusions over large areas is also possible in various parts of the ocean bottom.

In accordance with that stated above, Layer two of the standard section of the ocean bottom, possessing velocities on the order of 6.40 to 6.60 km/sec, is probably analogous to the so-called "granite" layer of the continental crust, although it is found in somewhat different environments. Layers with velocities of up to 5.5 or 5.6 km/sec, detected in the bottom section of abyssal parts of the ocean, more probably represent normal, consolidated, sedimentary rocks of such types as sandstone and limestone.

From all the statements about the quality of the measured heat current beneath oceans and continents and from known geologic data, it is possible to draw some conjectural conclusions:

1. The upper parts of the crust in continental and oceanic regions are characterized by differences in the physical state of the crust-forming material, but it is doubtful whether this indicates fundamental differences in the petrographic composition of the crust-forming rocks.

2. Parts of the crust, at present beneath ocean waters and layers of sedimentary rocks, are characterized by higher velocities of elastic waves in comparison, probably, with petrographically similar layers of the earth's continental crust, by virtue of the fact that crustal rocks in abyssal parts of oceans have experienced for many tens of millions of years the additional pressure of the column of ocean water, with a depth of up to 6000 m, and in places, of up to 10 or 11 thousand km in the trenches.

The expressed assumptions need additional confirmation by facts from the direct study of rocks in deep-seated environments (with the help of deep boreholes) and the experimental study of the physical (especially the velocities of the passage of longitudinal waves) properties of all kinds of rocks under high pressure and temperature conditions.

SOME FURTHER PROBLEMS OF GEOLOGIC AND GEOPHYSICAL RESEARCH

The examination of geophysical data on the structure of the crust and the attempts at geologic interpretation permits a high value to be placed on the attainments of geophysics in the field of exposing the differences in the physical state of matter within different parts of the crust. At the same time, it is quite impossible to agree in every case with the attempts to identify these indicated differences in the physical state of matter within the crust with the petrographic composition of the crust-forming rocks. In exactly the same way it is also necessary to consider as premature the attempts, based on such an identification, at reconstructing geologic and petrologic processes from the time of formation of the crust up to the present day.

Bearing in mind that B. Gutenberg and many other prominent geophysicists are not inclined to identify the various "layers" of the crust, characterized by different velocities of elastic waves, with differences in petrographic composition of these "layers", one should hope that geologists will also cease to recognize the conventional names "granitic", "basaltic" and "peridotitic" in a literal sense.

The basic source of errors in the petrographic interpretation of geophysical data consists of the fact that, in the first place, geophysical and geologic research is often undertaken separately, and, secondly, that the verified basis for the proper interpretation of changes in the complex of physical properties of different rocks under high pressure and temperature conditions indigenous to the deep layers of the crust has yet to be created experimentally. Such properties

of rocks as the velocities of the passage of longitudinal and elastic waves, rigidity, resistance to fracture, flow, the transition to other phase states, etc., have been very little studied.

The study of the structure at depth within the crust and the laws of its development, including the periodicity of geologic processes, is a complex problem which can only be resolved by the joint efforts of geologists, geophysicists and petrologists during the course of a large program of both experimental research and the sinking of specifically oriented boreholes to maximum depths within the areas correspondingly selected for study.

The project developed by American scientists for drilling through the ocean bottom in an abyssal region with the aim of reaching the Mohorovicic discontinuity and penetrating beyond this into the earth's ultrasimatic "mantle" is a positively complex and grandiose task, especially in terms of technical accomplishment.

The attainment of this goal, termed the "Moho" project — the sinking of a borehole to 10 km in an abyssal part of the ocean — will undoubtedly permit light to be thrown on some very important but also, from the viewpoint of geology, debatable problems, as, for example, the primordial nature of the oceans, geologic or petrographic reasons for a discontinuity in a petrographically separate layer of the crust in relation to the change in physical properties, and many other problems of contemporary geology, oceanography, geophysics and, perhaps, astronomy.

But the problem of the deep structure of the crust also possesses many other, more concrete aspects and questions that are very essential for contemporary geology.

It is especially important to advance our knowledge of deep parts of the crust in order to explain the mechanism of the origin and development of magmatic processes within the crust that are closely connected with tectonic and ore-forming processes. The complex problem Magmatism and the Deep Structure of the Earth's Crust, approved by the All-Union Petrographic Conference of 1958, must therefore be considered one of the most important problems of present-day geology.

One may tentatively consider these basic trends in the development of this problem:

1. The question of the genesis of magma, its origin in various deep geospheres, its physical nature in terms of contemporary notions on the structure of matter and its migrational capacity in different environments. The problem is resolvable by complex comparative methods of petrology, volcanology and geophysics, and also experimentally. It is thereby essential to study geologically, magmatic cycles and their relationship to the tecto[nics] of various regions, and also to enlist absolute age data as criteria for assessing mechanisms of genesis and alteration of magmas within the bowels of the earth.

Special, in particular geophysical, investigations of present volcanic eruptions are necessary, in order to create a basis for assessing the genesis of their melts and the peculiarities of their alteration.

It is extremely important to study the distribution of radioactive elements in igneous rocks as a possible factor in the influence of radioactive decay on the genesis of magmatic melts.

2. Questions of tectonics and magmatism: The explanation of the operating mechanisms of magmatic processes in tectonically different zones of the crust — zones of folding and platform areas. The correlations of volcanic and magmatic processes and their connection with various types of movement. The comparative study of: a) magmatic complexes of zones of folding, and b) magmatic complexes of platform regions. The disposition of granitoid, basic and ultrabasic formations in geologic structures, and the probing of the extent of their depth with the aid of geophysical methods.

3. Peculiarities during the course of magmatic processes in relation to the specific conditions for the period of formation of a given magmatic body. The mechanism of intrusion of magmatic processes into upper structural levels.

The genetic connection between volcanic and magmatic processes: the role of sub-volcanic processes in the genesis and localization of magmatic mineralization, e.g., in the formations of the Caucasus, the Maritime region, the Baykal region and the Carpathians.

4. Specific contact-metasomatic processes in connection with the different forms of magmatism. The influence of the solidification depth, body form, magmatic composition and other factors on the intensity and nature of contact-mineral formation in different intrusive[s]. The exposure by geophysical methods of the for[m] of magmatic bodies and the depth of their occurrence.

The role of metasomatic processes (in the broadest sense) in petrogenesis. The appraisal of the significance of granitization, basification and other processes in areas that are the most representative in these respects, utilizing "geochemical tracers" and crystal optics.

In order to accomplish these co-geophysical investigations, it is necessary first of all to

te an area in which the geologic structure sbeen clarified. The Caucasus may, for nple, be such an area. Here the joint in- igations of petrologists, structural geolo- s and geophysicists, applying the methods eismic probing, gravimetry, and magnetom- , in conjunction with the boring of deep holes with experimental research into the physical perties of particular rocks under various litions of pressure, water-saturation and perature, may yield vital results for many lematic questions of contemporary petrology geology. This is true because the various ictures of the Caucasus zone are distin- shed by the specific character of their con- uent strata.

n particular:

1) In some batholiths, masses of ancient cynian granites are exposed, with roof dants of an incompletely digested substratum ocks with Caledonian structures.

2) In others, there are outcrops of asso- ions of crystalline rocks like the Middle edonian massifs (basic and granitic forma- s), bordered by Hercynian crystalline for- tions.

3) Finally, the presence of the same for- tions is known from additional zones, but y are covered by a sedimentary Mesozoic Cenozoic deposit or by thick deposits of lavas variable composition.

4) There are the zones of depressions, com- sed for a considerable depth of sedimentary ks. It is essential here to determine the th of occurrence of the crystalline basement.

5) Young Mesozoic and Cenozoic intrusive mations are encountered which have not dergone any later processes; the Tyrnyauz rusion, for example, is revealed by the tural topography and by boring to a depth of re than 1.5 km (its total area is 10 km^2). obing by geophysical methods to the bottom this "pipe" of magmatic rocks — granites, ose density increases by approximately 2 to ; in the indicated vertical section, would be much general geologic interest. The same ay be said for the Pyatigorsk laccoliths, vealed by boring to a depth of about 1 km ithout any particular change in their petro- aphic appearance).

Valuable ore deposits are associated with e pegmatite bodies enumerated above. The vestigations may establish the regularity of eir formation and distribution. It may be orthwhile to study these deposits by deep illing to depth of 10 kilometers.

6) Of extreme importance, and requiring eophysical investigation, is the structural study and deep tracing of eruptions of magmatic material in strata with variable competence. There are facts pointing to the formation of intrustions and extrusions of tuffs in feebly competent strata like the clays of Maikop or those of the Lias, accompanied by the formation of ignimbrite, and to the formation of holocrystalline rocks in environments with a hard substratum.

7) It is possible to study volcanic formations like explosion-breccias and the mechanism of their ejection (explosion-pipes). It is important to ascertain the depth of occurrence of the magmatic rocks proper beneath such breccias. The organization of a deep-boring program would be expedient for these specific problems alone.

The work of geologists and geophysicists must be combined with:

1) Optical and X-ray investigations of the rock-forming minerals of diversely-aged formations;

2) geochemical study of the specific character of formations with variable ages;

3) study of silicate systems and their volatility under high-temperature and pressure conditions;

4) investigations of the physical parameters of typical rocks from the Caucasus of from any other area adopted for study (in accordance with the geophysical profiles) — their elastic properties, rigidity, permeability and porosity at different pressures and temperatures.

In particular, it is extremely important to continue and expand research on the velocities of longitudinal waves in different rocks at different pressures, and in the presence of water saturation, like those carried out by V. B. Sologub, A. Ya. Galushko and others at the Institute of Geological Sciences of the U.S.S.R. Academy of Sciences [23], by A. Laughton [42] and E. Hamilton [37] on deep-sea sediments, and by Yu. V. Riznichenko [21] and D. Hughes [39] on solid rocks of various kinds.

It is necessary to enlarge the group of physical properties of rocks that have been studied and to continue the important work carried out at the IGYeM Laboratory of the Physical Properties of Rocks (B. V. Zalesskiy and B. P. Belikov).

An increase in the resolving power of geophysical methods is important for these concrete aims. In this respect the research of I. S. Berzon on high-frequency seismic methods is interesting. It has been proved that a large number of reflecting and refracting boundaries can be distinguished during the recording of high-frequency seismic waves.

It is quite natural that, side by side with the study of the Caucasus as a geologically more or less well-studied territory, diverse and complex geologic and geophysical work and the application of deep boring in Kamchatka or the Kurile Islands, areas of presently active geologic processes, must certainly be arranged.

In order to carry out this research, it is very necessary for industry, and also for the scientific associations, branches and higher institutes of the academies of the Republics, to participate in the execution of the work. The degree of participation of various associations will depend on the chosen objective (territory) and on the details of the elaborated program of research.

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SIGNIFICANCE OF DATA ON THE RADIOACTIVITY AND THERMAL CONDUCTIVITY OF ROCKS IN METALLOGENIC INVESTIGATIONS[1]

by

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In this article temperatures for the deeper part of the crust are estimated, with an account of the differing radioactivity and thermal conductivity of rocks.

The author comes to the conclusion that the distribution of radioactive elements in igneous rocks and the thermal system of the crust confirm the correctness of the empirical scheme outlined by Yu. A. Bilibin for the development of mobile belts of magmatism, and that a large role is played in the development of magmatic activity by the low thermal conductivity of sedimentary rocks, favoring a considerable accumulation of heat in various local structures of the crust.

* * * * *

The close interdependence of geologic processes taking place in the crust has been studied in greatest detail by S. S. Smirnov and Yu. A. Bilibin, and has been based on the principles of metallogenic analyses elaborated by them. The practical application of a new approach to the study of patterns in the geologic development of the crust has permitted a solution to be found for important scientific problems and help to be rendered in the development of the mineral-raw material base of the Soviet Union.

Somewhat generalized patterns of distribution of intrusive complexes and extrusive formations in space and time were outlined in the course of metallogenic investigations within different fold regions, these being best reflected in the scheme for the development of mobile belts of magmatism elaborated by Yu. A. Bilibin [4].

No accurate basis for the exposed patterns of magmatic activity is possible without a clarification of the thermal system of the crust. The main source of thermal energy, in the opinion of most research workers, is radiogenic heat, continually generated as a result of the radioactive decay of uranium, thorium and potassium. Many hypotheses [2, 3, 13, 22, 24] have appeared in connection with the discovery of radiogenic heat, in which attempts are made to explain the causes of the magmatic foci and the development of processes of folding. A general defect in a large part of these hypotheses is the underestimation of the significance of the abruptly-differing thermal conductivity of rocks constituting the crust, which leads at times to unsubstantiated or inaccurate conclusions.

Before proceeding to clarify the thermal system of different structural zones in the crust, we will briefly examine some features in the geologic and metallogenic development of platform and geosynclinal areas.

On platforms a cover of feebly-metamorphosed sedimentary deposits is mostly observed, with a negligible thickness (usually not more than 2 to 4 km) and occurring on Precambrian rocks or on intensely disturbed and metamorphosed formations of a Paleozoic or Mesozoic age. Magmatic activity is very weakly displayed here. The igneous rocks are chiefly ultrabasic, basic and alkalic varieties.

In contrast to platforms, geosynclinal zones are characterized by a considerably greater amplitude of sagging. The thickness of sedimentary rocks produced through the formation of these zones reaches 10 to 15 km and more. A more or less definite sequence in the magmatic activity is noted [4] during the development of these zones and the fold areas arising in them. At the onset of strictly geosynclinal conditions (initial and early stages in the development of the mobile belt, according to Yu. A. Bilibin) there takes place an extrusion of basic and intermediate extrusives and an injection of basic and ultrabasic intrusives. The supply zones for the magmatic foci in this period are located, apparently, within the peridotite and basalt layers. In the middle stage of development of the mobile belt, when the overall thickness of sedimentary rocks

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[1]Znacheniye dannykh o radioaktivnosti i teploprovodnosti gornykh porod pri metallogenicheskikh issledovaniyakh.

attains maximum values, intrusive granitoid bodies are formed. This testifies to the position of the supply zone of the magmatic foci principally in the granite layer. The main phases of folding and crustal deformation of the whole geosynclinal zone, wherein the old region is developed, are connected with this period of evolution of the mobile belt. Subsequently, in the later and closing stages of development of the mobile belt, small granitoid intrusions, with an increased basicity, and extrusives of variable composition, are formed. The mixed composition of the igneous rocks testifies to a certain sinking of the supply zone of the magmatic foci to the boundary of the basalt and granite layers. It is necessary to note also the existence of a more ancient complex of intrusions, having a definite chemical and metallogenic resemblance to intrusive rocks of the later and final stages of development. The formation of this complex takes place at the end of the early stages of development of the mobile belt.

According to Yu. A. Bilibin [4], the above-noted sequence of magmatic activity was associated with the definite migrational character of the supply zones of the magmatic foci within the peridotite, basalt and granite layers. The distribution of radioactive elements in igneous rocks (Fig. 1), arising during the development of the mobile belt, also testifies to the regular migration of these supply zones in the crust. (The factual data based on this scheme were obtained from studying the radioactivity of rocks from fold regions of Kazakhstan, Altay and Siberia.)

Proceeding from the uranium and thorium content in the intrusive and extrusive formations of mobile belts, one may conditionally distinguish two magmatic "cycles" which resemble one another in general features and which correspond to a complete change in the rock basicity.[2] (The scheme cannot be matched with the universal scheme and they may substantially deviate from each other.)

The first magmatic "cycle" includes igneous rocks of the initial, early and middle stages of development of the mobile belt, and is characterized by a gradual increase in the uranium and thorium content of the younger rocks. Only in dikes of a basic, intermediate and, at times, acidic composition is the concentration of these elements somewhat lowered. During the period of formation of igneous rocks of the first magmatic "cycle" the fusion sources probably rise to the highest levels of the crust, since the intrusion of enormous masses of granitoid magma, containing high concentrations of radioactive elements, is associated with this "cycle" (middle stage of development of the mobile belt).

The second magmatic "cycle", as the first, is characterized by the presence of feebly radioactive igneous rocks at the beginning and end of the "cycle". This "cycle" comprises rocks of

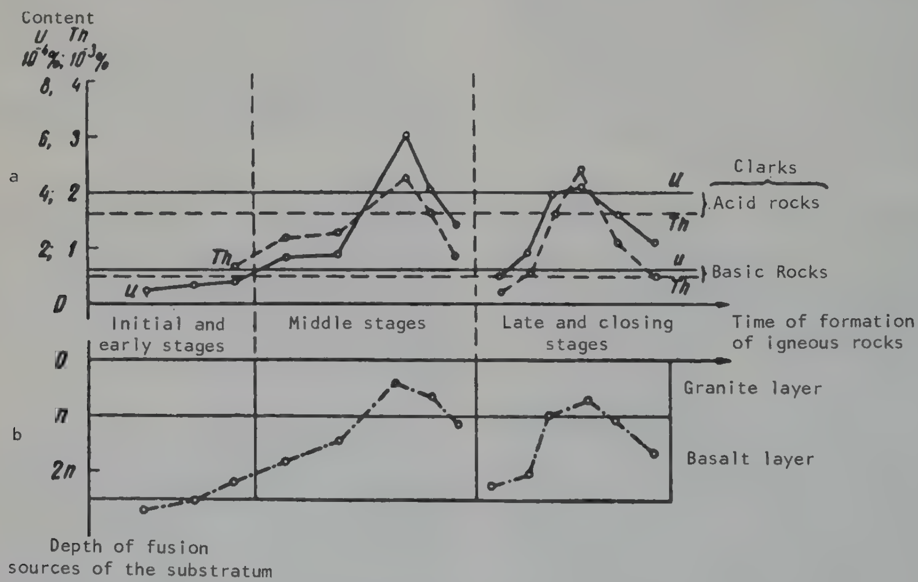

FIGURE 1. Distribution of radioactive elements in igneous rocks (a) and an approximate scheme for the migration of the supply zones of the magmatic foci (b) in the crust during different stages of development of mo mobile belts.

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[2]The magmatic "cycles" in question cannot be identified with magmatic cycles. A "cycle" usually includes several complexes.

the late and closing stages of development of the mobile belt.

With an account of the data cited in the literature about the uranium and thorium content of rocks of the granite and basalt layers [6, 23, ?], it is possible to outline an approximate scheme for the migration of supply zones of the magmatic foci which conforms to Yu. A. Bilibin's scheme [4] for the development of magmatism.

The results of metallogenic investigations in different structural zones of the crust show that there is a certain relationship between the location of the supply zones of the magmatic foci and the thickness of weakly metamorphosed and only slightly dislocated sedimentary deposits. In fact, the supply zones of the magmatic foci in geosynclinal areas are situated at a higher level within the crust, as a rule, than is the case in platform areas. During the course of development of mobile zones, the fusion sources rise to higher levels as the thickness of sedimentary deposits increases.

In the subsequent explanation of the causes of this phenomenon, we will take into account the fact that not only radiogenic heat by itself, but also the environment in which its emission and accumulation takes place, is of great importance during the development of the crust.

THERMAL CONDUCTIVITY OF ROCKS

In contrast to the other physical properties of rocks, their thermal conductivity has been very poorly studied; it is extremely difficult to establish precise values for the coefficient of thermal conductivity K.

According to H. Jeffrey [25], the mean value for thermal conductivity equals:

sedimentary rocks	-0.008 cal/cm· sec· degrees
granites	-0.006 "
basalts	-0.004 "

i.e., it decreases with depth.

Subsequently this position was not confirmed, factual material having been obtained which testified to the increase of thermal conductivity with depth [16]. Mean coefficients of thermal conductivity, equal to 0.006 or 0.003 cal/cm· sec· deg, are used by many authors in their calculations.

Allowing for the equality of thermal currents in different parts of the earth and for the different values of the geothermal gradient, S. A. Kraskovskiy takes the coefficient K as equalling:

crystalline rocks	-0.006 cal/cm· sec· deg
sediments	-0.002 "

The most complete factual material on the thermal conductivity of rocks is given by F. Birch [3, 21] and S. A. Kraskovskiy [8 - 12]; generalized summaries have been made by Ye. A. Lyubimova [14, 15], V. A. Magnitskiy [16] and others. A table of the thermal conductivity of rocks has been compiled by us from the accounts of various authors, in this table, the content of radioactive elements[3] and the generation of heat within different layers of the crust (Table 1) is also shown.

According to the data of V. A. Magnitskiy, the thermal conductivity of rocks of the deeper layers amounts to 0.02 to 0.05 cal/cm· sec· deg.

As is evident from the table, sedimentary deposits are characterized by low values for the coefficient K, i.e., these rocks are a kind of heat insulator. Their thermal conductivity increases, apparently, according to the measure of increase in the degree of metamorphism, approaching the values for crystalline rocks. Only the mean ranges of values of the coefficient K are shown in the table. In fact the thermal conductivity of crystalline rocks of the granitic layer ranges within broader limits — 0.006 to 0.016 cal/cm· sec· deg.

ACCUMULATION OF HEAT BENEATH THE COVER OF SEDIMENTARY DEPOSITS

The factual material collected up to the present time on the thermal system of the crust is still comparatively meager. Only a few measurements of the value of the geothermal gradient and the heat flow have been undertaken on various continents and in the majority of ocean basins. The data of some determinations of the geothermal gradient q, in m/deg, are given on the map (Fig. 2). This map also distinguishes the regions in which crystalline rocks of the Precambrian and Paleozoic, Mesozoic and Cenozoic folded formations outcrop, as well as areas where these rocks are covered by feebly metamorphosed sedimentary deposits of the platform type (the tectonic scheme of M. V. Muratov was used when defining these zones).

It is evident that values of the geothermal gradient are at a maximum of 80 to 150 m/deg within regions (shields) where the crystalline basement is exposed (Baltic, Canadian and African shields). If it is assumed that values of the geothermal gradient remain constant at different depths or change very little, then the temperature at a depth of 12 to 15 km amounts in all to 100 to 200°.

Quite different conditions for the thermal system in the upper parts of the crust are

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[3]The content of radioactive elements is quoted from the data of A. P. Vinogradov [6], L. V. Komlev, C. Davidson [23] and others.

TABLE 1

Name of layer	Depth of upper and lower boundaries (km)	Content of radioactive elements (%)	Mean density (g/cm^3)	Generation of heat P (cal/cm^3·sec)	Mean coefficient of thermal conductivity K (cal/cm·sec·deg)
Layer of sedimentary rocks	0—12	$U=2.5\cdot10^{-4}$ $Th=1.0\cdot10^{-3}$ $K=2.0$	2.2	$3.0\cdot10^{-13}$	0.003
Granitic	0—40	$U=3.5\cdot10^{-4}$ $Th=1.4\cdot10^{-3}$ $K=2.8$	2.6	$5.1\cdot10^{-13}$	0.006—0.009
Basaltic	40—70	$U=0.9\cdot10^{-4}$ $Th=0.4\cdot10^{-3}$ $K=1.0$	2.8	$1.5\cdot10^{-13}$	0.006—0.009
Peridotitic	70—200	$U=0.1\cdot10^{-4}$ $Th=0.1\cdot10^{-3}$ $K=0.3$	3.2	$0.3\cdot10^{-13}$	0.008—0.010
Underlying	200—800	$U=0.02\cdot10^{-4}$ $Th=0.02\cdot10^{-3}$ $K=0.1$	3.5	$0.06\cdot10^{-13}$	0.009—0.012

are observed in areas where sedimentary deposits of the platform type are developed (Russian platform, West Siberian lowlands and others). The value of q in these areas is considerably less (20 - 40 m/deg), than is the case in the shields. With such a value for the geothermal gradient, the temperature beneath the layer of sedimentary deposits, 12 to 15 km thick, will amount to 300 to 400° and more.

Regions of Paleozoic and, probably, of Cenozoic folding, within which values of the geothermal gradient vary from 40 to 100 m/deg, occupy an intermediate position with respect to the character of the thermal system, and, finally, the value of q in zones of Alpine folding is equal to 15 to 25 m/deg. The heat flow in different parts of the earth is approximately the same and on an average amounts to 1.0 to $2.0\cdot10^{-6}$ cal/cm^2·sec.

Thus, even from a simplified calculation based only on the value of the geothermal gradient observed in different parts of the earth, it is evident that the temperature of rocks from the granite and basalt layers beneath a cover of sedimentary deposits is considerably higher in comparison with the temperature of those zones where sedimentary deposits are absent. A precise calculation of temperatures within the bowels of the earth, allowing for every factor (irregular distribution of radioactive elements in rocks, thermal conductivity and conditions of mobility), presents considerable difficulties. Therefore we will confine ourselves to examining simplified schemes which correspond to definite structural elements of the crust, and we will make a number of assumptions:

1. Radioactive elements are evenly distributed in the separate layers of the crust, and they are the principal sources of thermal energy.

2. The thermal conductivity of rocks of the granite, basalt and peridotite layers is identical and equals 0.008 cal/cm·sec·deg.

3. Crustal areas are characterized by a steady thermal system.

The calculations are derived for models of shields, platforms and mobile belts in initial, early and middle stages of development.

When determining the thermal system of the crust, we will profit from the formulas obtained by A. N. Tikhonov [19] for a two-layer, heat-radiating medium by solving the equation

$$\frac{\partial}{\partial x}\left(k\cdot\frac{\partial u}{\partial x}\right)-c\rho\,\frac{\partial u}{\partial t}=-A.$$

If a stationary process[4] is examined, then

$$\frac{\partial}{\partial x}\left(k\cdot\frac{\partial u}{\partial x}\right)=-A.$$

The solution of this equation may be used also for calculating the temperature of three- and four-layer media, provided that the coefficients of thermal conductivity for Layers l_2, l_3 and l_4 are equal ($k_2=k_3=k_4$). When determining $U_0(x)$ for a three-layer, heat-radiating medium (Fig. 3), we will replace Layers l_2 and l_3 by one with a thickness of l_2+l_3 and having the very same coefficient of thermal conductivity $k_2{}^1=k_2+k_3$ and a generation of heat $P_1=P_3$. While examining also a certain two-layer medium in which $P_1''=0$, $P_2''=P_2$ and $P_3''=0$, we will

[4]The maximum value of the temperature, which may be obtained from $t_1\geqslant100$ million years, the time of geosynclinal development, will interest us. In this case $1\leqslant Q_0/Q_1\leqslant1.12$, i.e., the heat system will differ very little from the stationary system.

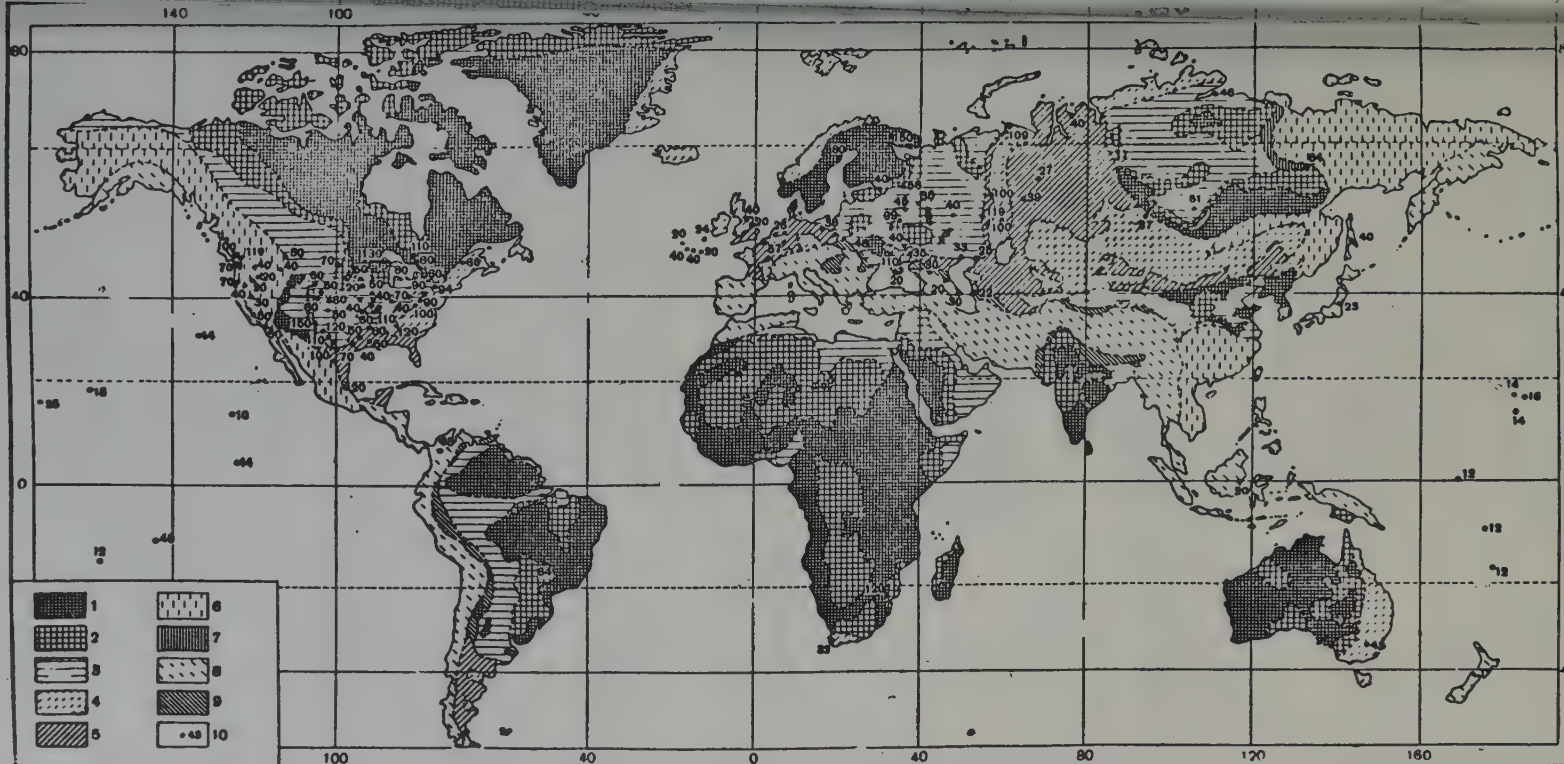

FIGURE 2. Values of the geothermal gradient in different geologic structures of the crust (compiled from the data of S.A. Kraskovskiy, F. Birch and others, and based on the tectonic scheme of M.V. Muratov).

1 - outcrops of Precambrian rocks (shields); 2 - regions of development of Precambrian rocks covered by a thin mantle of sedimentary deposits (slopes of shields); 3 - depressed Precambrian platforms with a thick cover of sedimentary deposits; 4 - regions where Paleozoic folding is exposed at the surface; 5 - regions of Paleozoic folding screened by a cover of platform sediments; 6 - regions of Mesozoic folding; 7 - Mesozoic marginal flexures; 8 - regions of Cenozoic folding; 9 - marginal flexures of the Alpine belt; 10 - survey points and values of the geothermal gradient in m/deg.

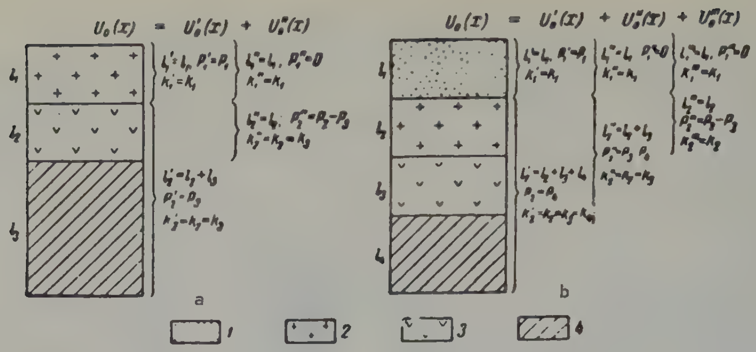

FIGURE 3. Sequence of the replacement of three-layer (a) and four-layer (b) radioactive media by two-layer media in the calculation of temperature

1 - sedimentary deposits; 2 - rocks of the granite layer; 3 - rocks of the basalt layer; 4 - formations of the peridotite layer.

introduce a correction for additional radiation P_2 by the layer.

The solution necessary to us will be equal to their sum:
$U_0(x) = U_0'(x) + U_0''(x)$ — three-layer medium and $U_0(x) = U_0'(x) + U_0''(x) + U_0'''(x)$ — four-layer medium. ($U_0'(x)$, $U_0''(x)$ and $U_0'''(x)$ are not derived from U (x), but by independent solutions of the equation of thermal conductivity.

Using this method of calculation for a four-layer, heat-radiating medium, we will obtain:

$$\text{for } 0 \leqslant x \leqslant l_1 \quad U_0(x) = \frac{P_1}{k_1}\left(l_1 x - \frac{x^2}{2}\right) + \frac{(P_2 - P_3)\, l_3}{k_1} x + \frac{(P_3 - P_4)(l_2 + l_3)}{k_1} x + \frac{P_4 (l_2 + l_3 + l_4)}{k_1} x;$$

$$\text{for } l_1 \leqslant x \leqslant l_1 + l_2 \quad U_0(x) = \frac{P_1 \cdot l_1^2}{2k_1} + \frac{P_2 l_1 \cdot l_2 + P_3 \cdot l_1 \cdot l_3 + P_4 \cdot l_1 \cdot l_4}{k_1} + \frac{P_2 - P_3}{k_2}\left[l_2 \cdot (x - l_1) - \frac{(x - l_1)^2}{2}\right] + \frac{P_3 - P_4}{k_3}\left[(l_2 + l_3)(x - l_1) - \frac{(x - l_1)^2}{2}\right] + \frac{P_4}{k_4}\left[(l_2 + l_3 + l_4)(x - l_1) - \frac{(x - l_1)^2}{2}\right];$$

$$\text{for } l_1 + l_2 \leqslant x \leqslant l_1 + l_2 + l_3$$

$$U_0(x) = \frac{P_1 \cdot l_1^2}{2k_1} + \frac{P_2 \cdot l_1 \cdot l_2 + P_3 l_1 \cdot l_3 + P_4 l_1 \cdot l_4}{k_2} + \frac{(P_2 - P_3) \cdot l_2^2}{2k_2} + \frac{P_3 - P_4}{k_3}\left[(l_2 + l_3)(x - l_1) - \frac{(x - l_1)^2}{2}\right] + \frac{P_4}{k_4}\left[(l_2 + l_3 + l_4)(x - l_1) - \frac{(x - l_1)^2}{2}\right];$$

$$\text{for } l_1 + l_2 + l_3 \leqslant x \leqslant l_1 + l_2 + l_3 + l_4$$

$$U_0(x) = \frac{P_1 \cdot l_1^2}{2k_1} + \frac{P_2 \cdot l_1 \cdot l_2 + P_3 \cdot l_1 \cdot l_3 + P_4 \cdot l_1 \cdot l_4}{k_1} + \frac{(P_2 - P_3)\, l_2^2}{2k_2} + \frac{(P_3 - P_4)(l_2 + l_3)^2}{2k_3} + \frac{P_4}{k_4}\left[(l_2 + l_3 + l_3)(x - l_1) - \frac{(x - l_1)^2}{2}\right]$$

and for $x > l_1 + l_2 + l_3 + l_4$

$$U_0(x) = \frac{P_1 l_1^2}{2k_1} + \frac{P_2 l_1 \cdot l_2 + P_3 l_1 \cdot l_3 + P_4 \cdot l_1 \cdot l_4}{k_1} + \frac{(P_2 - P_3)\, l_2^2}{2k_1} + \frac{(P_3 - P_4)(l_2 + l_3)^2}{2k_3} + \frac{P_4 (l_2 + l_3 + l_4)^2}{2k_4}$$

n a similar way it is possible to find the ution of U_0 (x) for any number of radio- ve layers.

When explaining the thermal system of the in structural elements of the crust, it is npletely adequate to confine oneself to exam- ng a four-layer, heat-radiating environment.

The heat flow at the surface of the earth and geothermal gradient in the upper layer was ermined from the formulas:

$$= P_2 \cdot l_1 + P_1 \cdot l_2 + \ldots + P_n \cdot l_n \text{ and } q = \frac{K}{Q}.$$

e value of q was also checked with the tem- rature values obtained by means of calcula- n.

The temperature at various depths in the per part of the earth was computed for six es of structures by calculating the radio- nic heat generated in rocks of the granite, salt and periodotite layers. In the opinion a number of authors [7, 15], processes[5] ing place to a depth of 800 to 900 km influence e thermal system of the crust.

The first type of crustal structures (rocks of e basalt layer, with a thickness of 10 km., st on formations of the peridotite layer).[6] In first approximation this model of the crust aracterizes primary geosynclinal depressions. e area of the Pacific Ocean may be, appar- tly, assigned to these kind of zones. In fact, cording to seismic data, an extremely thin to 10 km) layer of rocks is noted here, being aracterized by a propagational velocity for ngitudinal waves of 6.5 to 7.5 km/sec [13, 7]. Such velocities are observed in forma- ons of the basalt layer. Over a large part of e area of the Pacific Ocean the basalt layer is overed by sedimentary deposits having a small ickness (1 to 2 km).

The calculations (Table 2 and Fig. 4) show at within such zones a very small increase of temperature with depth is observed (q = 130 - 150 m/deg at k = 0.008 cal/cm· sec· deg and q = 150 - 170 m/deg at k = 0.01 cal/cm· sec· deg).

Making a correction for the heat radiation of deep layers of the earth, the temperature at depths of 50 to 60 km amounts in all to 400 to 500°. Therefore the emergence of foci of fusion here at depths of less than 50 or 60 km is practially excluded.

The heat flow at the surface of the basalt layer amounts to 1.3×10^{-6} cal/cm^2· sec with an allowance for the correction.

The presence of a thin cover of sedimentary deposits (Pacific Ocean) does not substantially change the temperature value at different depths, but the geothermal gradient near the surface in this case will be abruptly different. Because the thermal conductivity of sedimentary deposits within the Pacific Ocean is very low (0.001 to 0.002 cal/cm· sec· deg) the geothermal gradient, resulting from the overall value of heat flow ($Q_{total} \approx 1.3 \times 10^{-6}$ cal/cm^2· sec in the presence of sedimentary deposits), will amount to 10 to 20 m/deg.

Taking into account the correction for the heat radiation of deep horizons and the layer of sedimentary deposits, the values obtained for the heat flow are found to be in accordance with those observed in reality. The equality of ther- mal currents within oceanic depressions and continents ought to be explained, apparently, by the different volumes of rocks influencing the thermal system in various parts of the crust, and not by the differing content of radioactive elements, as many people believe [2, 7, 17]. In oceanic depressions which took a long time to form the depth of heat outflow will be greatest because in the upper portion of such structures develop formations with a high coefficient of thermal conductivity.

To the second type of crustal structure (sedi- mentary deposits with a 10 km thickness lie directly over the basalt layer of a similar thick- ness) may be assigned the geosynclinal zones whose formation took place on the basalt base- ment. Apparently a similar crustal structure is observed within certain island arcs of the Pacific Ocean.

The temperature at these very same depths in the second type of structure is considerably

[5] The content of radioactive elements, heat genera- on and other quantities characterizing the rocks of eep layers are shown in Tables 1 and 2.

[6] The thicknesses of sedimentary deposits and the anite and basalt layers are shown in Fig. 4, that of e periodotite layer being equal to 150 km.

TABLE 2

Temperature distribution at different depths in the earth's crust according to calculated data (within 2 to 5%)

Types of crustal structures	Temperatures (deg.) at depths (km.)													Q (cal/cm², sec)[1]	Geothermal gradient in surface zones (m/deg)
	2	4	6	10	15	25	50	100	140	150	160	180	>180		
1. Primary oceanic depressions (pre-geosynclinal period of development)	15	25	35	60	90	165	240	390	420	430	440	440	440	$0.6 \cdot 10^{-6}$ $(1.3 \cdot 10^{-6})$	130—150
2. Geosynclinal zones developed on a basaltic basement (initial and early stages of development of the mobile belt)	58	110	160	250	280	340	465	640	—	720	730	735	>735	$0.8 \cdot 10^{-6}$ $(1.2 \cdot 10^{-6})$	30—40
3. Geosynclinal zones developed on a granitic layer of small thickness (initial, early and possibly middle stages of development of the mobile belt)	95	185	265	420	485	560	695	885	—	—	1030	1040	>1040	$1.3 \cdot 10^{-6}$ $(1.7 \cdot 10^{-6})$	20—25
4. Geosynclinal zones developed on a granitic layer of considerable thickness (middle stages of development of the mobile belt)	140	275	410	660	840	1000	1200	1460	—	—	1600	1620	>1620	$2.0 \cdot 10^{-6}$ $(2.4 \cdot 10^{-6})$	15
5. Regions where Precambrian crystalline rocks (shields) and strongly metamorphosed Paleozoic and other rocks outcrop	25	55	85	135	175	230	380	550	—	—	680	680	>680	$1.1 \cdot 10^{-6}$ $(1.5 \cdot 10^{-6})$	70—80
6. Regions of Precambrian and Paleozoic folding screened by a cover of platform sediments	85	110	140	190	240	315	450	645	—	—	755	760	>760	$1.2 \cdot 10^{-6}$ $(1.6 \cdot 10^{-6})$	25
Correction for the heat radiation of rocks of deep layers with a thickness of 600 km (below the peridotite layer)	5	15	25	40	65	100	200	410	580	620	660	740	>740	$0.4 \cdot 10^{-6}$	

[1]The values of the heat flow, with an allowance for the heat radiation of the deep layers, are given in parentheses. A 1.5 times greater correction is introduced for oceanic depressions in view of the preferential development of rocks possessing a high thermal conductivity.

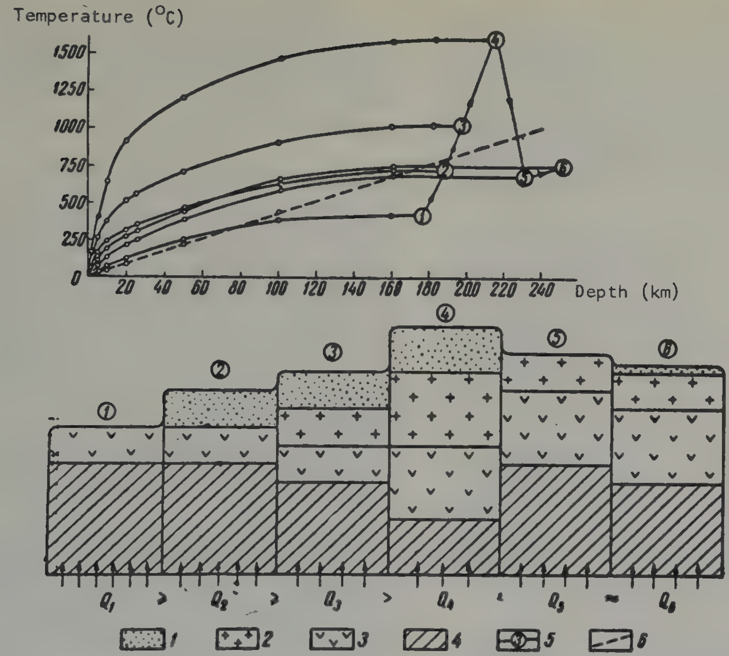

FIGURE 4. Thermal system in different structural zones of the crust.

1 - weakly metamorphosed sedimentary deposits; 2 - rocks of the granite layer; 3 - rocks of the basalt layer; 4 - formations of the peridotite layer; 5 - curve of the relationship of temperature to depth for corresponding types of crustal structures; 6 - curve of the relationship of temperature to depth on account of the heat radiation developed below the peridotite layer. Correction for the heat radiation of deep horizons in circles: 1 - first type of crustal structure (l_1 = 10 km, l_2 = 150 km); 2 - second type of crustal structure (l_1 = 10 km, l_2 = 10 km, l_3 = 150 km); 3 - third type of crustal structure (l_1 = 10 km, l_2 = 10 km, l_3 = 10 km, l_4 = 150 km); 4 - fourth type of crustal structure (l_1 = 10 km, l_2 = 20 km, l_3 = 150 km); 5 - fifth type of crustal structure l_1 = 10 km, l_3 = 20 km, l_4 = 150 km); 6 - sixth type of crustal structure (l_1 = 2 km, l_2 = 10 km, l_3 = 20 km, l_4 = 150 km.

igher than in the primary geosynclinal depressions. Thus, for example, the temperature t a depth of 50 to 60 km will already amount to 00 to 800°. The sites where the substratum is nelted within the peridotite layer[7] may, probaly, arise in this type of structure at depths of 0 to 70 km or at somewhat greater depths. The eothermal gradient and heat flow at the surface f this structural zone are equal to 20 to 30 m/ eg and 1. 2 x 10^{-6} cal/cm^2· deg respectively llowing a correction for the heat radiation of eep layers).

The third type of crustal structure (sedientary rocks with a thickness of 10 km rest n formations of the granite layer with a similar thickness) may characterize mobile belts in the initial and early stages of their development, i. e., when geosynclinal formation took place on a granitic basement. In individual cases it may also correspond to the middle stages of development of a mobile belt.

High-temperature regions in such crustal structures ascend to even higher levels. Thus, for example, the temperature at a depth of 25 to 50 km reaches 700 to 900°. The sites where the substratum is melted may already arise within the basalt layer.

The fourth type of crustal structure (sedimentary rocks with a thickness of 10 km rest on a granite layer of considerable thickness) corresponds to mobile belts in the middle stages of their development and is most typical of regions of young folding, within which (Alps, Carpathians, Himalayas, etc.) the crustal thickness 50 to 70 km, 20 to 30 km of this being part of the granite layer.

[7]According to research by O. Tuttle and N. Bowan 5], sites where the substratum is melted may, parently, arise at temperatures in excess of 800 or)°.

In these structures, the sites where the substratum is melted originate, apparently, at depths of 15 to 25 km, where the temperature, according to calculated data, amounts to 800 to 1500°. Thus, in the middle stages of development of the mobile belt the supply zones of the magmatic foci may be located within the granite layer of the crust.

The fifth and sixth types of structure characterize regions where there are outcrops of Precambrian crystalline rocks and strongly metamorphosed formations of a Paleozoic age (shields and platforms) without any mantle of sedimentary deposits (fifth type) and in the presence of a cover of sedimentary rocks of a platform type (sixth type). The abrupt decrease in temperature at corresponding depths is again noted within these structures. The formation of the foci of fusion here is possible only in the peridotite layer, but with a large thickness of highly radioactive rocks or sedimentary deposits they may be developed in the basalt or even granite layers.

Other sources of thermal energy (apart from radiogenic ones) were not taken into account (gravitational, solar, etc.) when determining the values of temperature at various depths. The introduction of heat from these sources appears, in all probability, to be small in view of the good convergence of the calculated data and results of the direct determinations of values for the heat flow and geothermal gradient (Table 2). Somewhat lower values of the geothermal gradient within shields (60 to 80 m/deg according to calculated data) are explained by the fact that the coefficient of thermal conductivity of the granite layer was taken to equal 0.008 cal/cm· sec· deg. At larger values of the coefficient K, the geothermal gradient will amount to 100 m/deg and more.[8]

Estimates of the temperature of mobile belts in the late and closing stages of their development are difficult, because the values of the coefficient of thermal conductivity of sedimentary rocks, subjected to epigenesis as a result of intensive golding, have not been precisely established. Tentative calculations show that, in comparison with the proper geocynclinal period of development of a mobile belt, a considerable outflow of heat is observed in this stage in consequence of the magmatic activity and increase in the thermal conductivity of sedimentary rocks. Therefore the sites where the substratum is melted experience a certain sinking and may be located near the boundary of the granite and basalt layers.

[8] According to the data of F. Birch [3, 21], the thermal conductivity of crystalline rocks may reach 0.010 to 0.016 cal/cm· sec· deg.

Proceeding from these calculated data, it is thus established that the accumulation of heat energy is observed beneath a cover of feebly disturbed sedimentary deposits possessing a low thermal conductivity.

Slow quantitative changes in the thermal system of the crust, taking place together with sedimentation, lead in the end to the genesis of centers of melting of the substratum within the peridotite, basalt, and granite layers and are the cause of development of intensive processes of magmatic activity in mobile belts. The thic the cover of sedimentary rocks and the surer t heat radiation, the greater is the accumulation thermal energy and the higher the level at whic the centers of fusion are situated. This, apparently, also constitutes the link between sedimentation and magmatism following from the metallogenic constructions of Yu. A. Bilibin.

The process of the migration of supply zones for the magmatic foci within the granite and basalt layers, about which Yu. A. Bilibin [4] ha written, becomes understandable in connection with heat accumulation beneath the cover of sedimentary deposits.

In the initial and early stages of developmen of the mobile belt, when the thickness of sedimentary deposits is small in comparison with the overall thickness during the middle stages of development, centers where the substratum is melted arise only within the peridotite and basalt layers (second and third types of structure). In fact, the most widespread igneous rocks in this phase of the geosynclinal system are hose of ultrabasic and basic composition. At the same time the centers of melting of the substratum in separate mobile belts may alread be situated within the granite layer by the early stages of development, under favorable conditions (thick granite layer and a layer of sedimentary deposits).

During the middle stages of development (fourth type, Fig. 4) when a thick deposit of sediments covers the formations of the granite and basalt layers, the zones of high temperature rise to higher levels in the crust. There are in this period all the conditions for the genesis of granite magmas which are found in most regions of folding.

Subsequently, after the appearance of the mai phases of folding, there is a considerable loss o heat. It is possible that together with magmatic processes the increase in thermal conductivity of sedimentary rocks, taking place in the course of their epigenesis, plays a large role in the dissipation of thermal energy. The centers of melting of the substratum undergo a certain sinking in the later and final stages of development of mobile belts, as a result of the intense dissipation of thermal energy. The dissipation of heat through magmatic activity and the

reasing thermal conductivity of sedimentary ks becomes so considerable that those parts the crust with intensely developed processes folding and magmatism gradually turn into bilized, platform areas.

CONCLUSIONS

1. During the development of mobile belts a finitely "cyclical nature" for the distribution uranium and thorium in igneous rocks is served, testifying to repeated movements of e supply zones of the magmatic foci within e granite and basalt layers. The character this movement agrees with the scheme of velopment for fold regions established by Yu. Bilibin.

2. Together with radioactivity, the low therial conductivity of sedimentary rocks plays a rge part in the development of magmatic actiity. Calculations show that there a considerle accumulation of thermal energy takes ace beneath a cover of feebly metamorphosed dimentary deposits. Thereby, the greater e cover of sedimentary rocks, the higher the vel at which the centers of melting of the subratum are situated. This probably also conitutes the link between sedimentation and agmatism which follows from the metallogenic onstructions of S. S. Smirnov and Yu. A. Bilibin.

3. Temperature values in the various stages development of mobile belts testify to the fact at in the initial and early stages, zones of gh temperature (possible centers for the meltig of the substratum) arise within the basalt nd peridotite layers, these being developed rincipally in the granite layer during the midle stage and near the boundary of the basalt and ranite layers in the late and final stages.

The disposition of these possible centers of nelting of the substratum corroborates the corectness of the scheme established by Yu. A. ilibin for the development of magmatism in nobile belts.

4. Metallogenic investigations which have xamined the totality of interrelated geologic rocesses reveal great possibilities for studying he general patterns of development of the crust. The more or less precise basis of patterns mpirically outlined during regional metallogenic investigations depends mostly on how much use is made of the results of geochemical and geophysical methods, together with those of geologic methods. Data on the thermal system of the crust, with whose corresponding changes he development of magmatic activity is connected, have a particular significance. The determination of temperature in the deeper part of the crust is also of value for studying processes of folding, for clarifying the magnetically-active zone of the earth and for solving other questions.

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ABSOLUTE AGE OF THE UPPER CRETACEOUS AND TERTIARY EXTRUSIVE AND INTRUSIVE ROCKS OF NORTHERN SIKHOTE-ALIN' AND THE MYAO-CHAN MOUNTAINS[1]

by

N. I. Polevaya and E. P. Izokh

Figures are given in this article for the absolute age of rocks from the Upper Cretaceous and Tertiary extrusive and intrusive series of northern Sikhote-Alin' and the Myao-Chan Mountains. The geologic age of the extrusive rocks, determined by finding a fossil flora, and also the age of the intrusives piercing them agree well with the data from the argon method. The data stated in this article testify to the possibility of applying the argon method for distinguishing Mesozoic and Cenozoic magmatic formations.

* * * * *

The determination of the absolute age of volcanic rocks directly containing organic remains by the argon method, and the age determination of intrusive rocks, whose time of formation has been estimated from stratigraphic data, is of great importance both for evaluating the precision of the method itself and for working out a scale of absolute geochronology. In this respect, the data stated below for two areas of the Far East are of interest: northern Sikhote-Alin' and the Myao-Chan Mountains (near the town of Komsomol'sk-na-Amur).

Age determinations were carried out with the assistance of V. D. Sprintsson, L. V. Shashukova and A. V. Mattes, by the volumetric method described by E. K. Gerling and using equipment designed at the VSEGEI [7]. All determinations were accompanied by the isotope analysis of argon separated from the rocks.

The following values for the potassium-decay constants were used for the age calculations: $\lambda_\beta = 4.72 \cdot 10^{-10}$ years^{-1} and $\lambda_k = 0.557^{-10}$ years^{-1}. These values are considered at the present time to be the most reliable [1] and are accepted for the most part in both Soviet and foreign laboratories. In this connection, the previously published data of one of the authors [3, 4, 5, 6] have been recalculated using new constants, which increases the ages obtained by approximately 8 to 10%.

1. NORTHERN SIKHOTE-ALIN'

Along part of the Komsomol'sk - Sovetskaya Gavan' railroad, between the stations of Sikhote and Kuznetovskiy Pereval, a sequence of Upper Cretaceous extrusive is exposed, lying discordantly on arenaceous shaly deposits whose Valanginian age has been proved by their fauna.

The extrusive sequence is subdivided into two series possibly separated by an angular unconformity. The lower series consists of amygdaloidal stony andesite porphyry, tuff and brecciated lava; the upper series is composed of ashy, crystalline and lithocrystalline tuff of quartz porphyry. In the lower part of the series of acidic extrusives, these plant imprints were detected: Metasequoia disticha (Heer) Miki, Taxites Obrikii Heer, Pinus sp. cf., P. hyperborea Heer, small fragments of Phyllites sp. cf. and Grewiopsis sp. According to the conclusions of M. I. Borsk, this flora is characteristic of both the Danian stage and the Paleocene.

If the data on the stratigraphy of extrusives in other areas of Sikhote-Alin' are taken into consideration, then the age of the acidic extrusives of this area is, in all probability, Danian.

Further to the south of Sikhote station there is a similar deposit of acidic extrusives, in which a flora was detected, pierced and intensely metamorphosed by the multi-phase Verkhnudominsk massif, composed of rocks of certain intrusive phases: 1) gabbro-diorite and diorite, 2) granodiorite, 3) granite porphyry and 4) fine-grained granite. Within the massif these rocks form somewhat intrusive bodies of a relatively monotypic composition which have sharp contacts with the other rocks. The sequence in

[1]Absolyutnyy Vozrast Verkhnemelouykh i Tretichnykh effuyeivnykh i intruyeiunykh porod Severnogo Sikhote-Alinya i khrebta Myso-Chan.

rock-formation is demonstrated by the presence of granodiorite veins in diorite and of granite veins in all the more basic rocks, as well as by observations on contact metamorphism and other features.

For the absolute age determination in the Kuznetsovskiy Pereval area we collected specimens of ashy and cryptocrystalline tuff of the quartz porphyry (Specs. 380-c, 380-b, 379-a), admixtures devoid of structural material, diorite from an intrusive body which is in immediate contact with acidic tuff and which has metamorphosed them, and also specimens of porphyritic granite (Spec. 53) forming the predominant part of the massif. The results of the absolute age determinations are given in Figure 1 and Table 1.

M. A. Favorskaya) Yu. M. Vdovin, Z. V. Potapova, E. P. Izokh and others).

Between Kato and Tuluchi stations extrusives of the Samarginian series are pierced and metamorphosed by the Tuluchi intrusive massif, in which diorite developed in the early phase and granodiorite in the late phase. Diorite and granodiorite xenoliths, of a type very similar to rocks of the Tuluchi massif, have been observed in extrusives of the Bargopolian series in the area of Akur. Thus, the age of this massif is established most probably as Paleocene.

In petrographic features and age, the rocks of the Tuluchi massif are comparable to those of the early phases of the Verkhneudinsk massif. This conclusion, and the stratigraphic data for

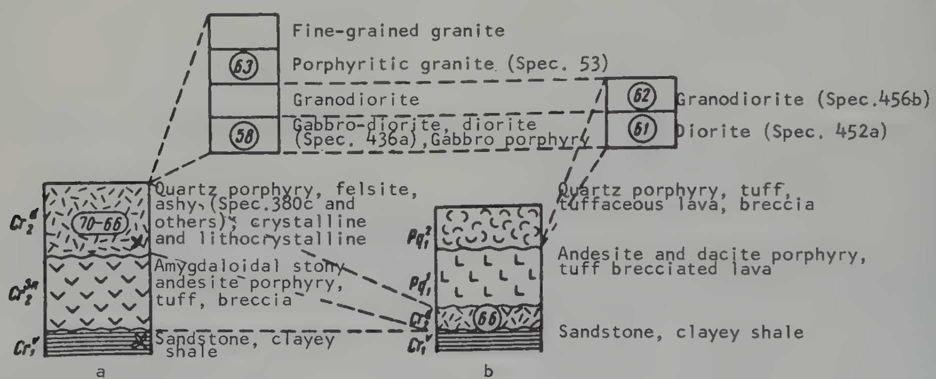

FIGURE 1. Classification of the age sequence of extrusive and intrusive rocks.

a - Kuznetsovskiy Pereval area, b - area of the stations of Kato, Kenada and Tuluchi on the Komsomol'sk - Sovetskaya Gavan' railroad.

A section of younger, Tertiary, extrusive formations is found some 60 to 70 km and more to the east, along the same railroad. At the base of the section, near Kenada and Kato stations, there is a deposit of felsite, quartz porphyry and thinly laminated tuff, very similar to the acidic extrusives of Kuznetsovskiy Pereval in appearance, composition and degree of deformation. It is overlain stratigraphically by andesite, andesite-dacite and dacite porphyry, tuff, brecciated tuff and lava. This stratum is comparable to the Paleocene Samarginian series of the Southern Maritime Region. Higher in the section, in the area of Tuluchi and Akur stations, there is a still younger stratum of quartz porphyry and tuff, comparable to the Paleocene-Eocene series of Bogopol' in the Southern Maritime Region.

The above-indicated succession of extrusive rocks has been observed by many geologists who have worked in this area (Yu. A. Ivanov,

these extrusives, agrees quite well with the absolute age determinations. We analyzed quartz porphyry tuff (Spec. 446-b) from a series resembling the quartz porphyry of Kuznetsovskiy Pereval and also granodiorite (Spec. 456-b) and diorite (Spec. 452-a) from the Tuluchi massif piercing the extrusive Paleocene series. The stratigraphic position of the studied specimens and their ages are shown schematically in Figure 1 b; the experimental data are reduced in Table 1.

It is evident from examining this table that the data of the argon method reflect well the geologic age and sequence of the analyzed specimens of intrusive and extrusive rocks. It is necessary to take into account the fact that the age interval studied by us is extremely small (Danian stage to the top of the Paleocene), and that errors in the argon method, connected with both the experimental technique and the possible leakage of argon from specimens during geologic time, may be of some importance here.

Table 1

Age of intrusive and extrusive rocks of northern Sikhote-Alin'

Sample Nos.	Name of Rock	Sample location	K. %	$K^{40} \cdot 10^{-5}$ g/g	$Ar^{40} \cdot 10^{-7}$ g/g	$\frac{Ar^{40}}{K^{40}}$	Age in million years
53	Porphyritic granite	Kuznetsovskiy Pereval	3.82	0.459	0.165	0.0036	63
436-a	Diorite	" "	1.93	0.232	0.074	0.0033	58
379-a	Quartz porphyry tuff	" "	2.40	0.288	0.115	0.0040	70
380-b	Quartz porphyry tuff	" "	2.96	0.356	0.134	0.0038	67
380-c	Quartz porphyry tuff	" "	2.58	0.310	0.116	0.0037	66
456-b	Granodiorite	Kato station	3.27	0.393	0.137	0.0035	62
452-a	Diorite	" "	2.24	0.269	0.093	0.0034	61
446-b	Quartz porphyry tuff	Kenada Station	3.80	0.456	0.168	0.0037	66

II. MYAO-CHAN MOUNTAINS

Upper Cretaceous extrusives are widespread in this area, being incorporated in the so-called Amutian series. At the base of the series occur quartz and quartz-bearing porphyry, tuff, brecciated tuff and tuffite, in which V.V. Onikhimovsk, I.Ya. Zytner and Z.P. Potapova have detected imprints of Cephalotaxopsis heterophylla Holl., C. microphylla laxa Holl., Sphenolepsis sternbergiana (Dunker, Schenk) and Phyllites sp. The upper part of the Amutian series is formed of massive pyroxene porphyry, resembling andesite and andesite-dacite in composition, and more rarely tuff and brecciated lava.

The Amutian series is underlain by tuffaceous and sedimentary deposits of the Kholdomian series, containing plant impressions characteristic of the top of the Lower Cretaceous, and is covered by Neogene basalt. According to the conclusions of M.I. Borsk and M.M. Koshman, the flora at the base of the Amutian series is Upper Cretaceous.

There are a large number of dikes and small intrusions in the area, composed principally of quartz gabbro, gabbro-diorite or monzonite-granodiorite, and to a lesser extent — granite. There also is the large, intricately-constructed, Chalbin massif which includes intrusive bodies of quartz gabbro, monzonite-granodiorite, monzonite-granite (i.e., granite with andesine-labradorite), porphyritic biotite-hornblende granite, coarse-grained biotite granite and fine-grained leucocratic granite.

Detailed petrographic studies permitted all intrusive rocks of the area to be assigned to one so-called Myao-Chan series, beginning with gabbro intrusions and ending with intrusions of the most acidic granite (Figure 2). Almost each of the above-named types of rocks in the area is represented by both highly equigranular varieties (in the Chalbin massif) and porphyritic modifications (in small intrusions and dikes). For many rock types the age relations with intrusive rocks of a different composition may be determined by direct observation, which enables one to speak of the regular development of intrusive magmatism from a basic to an acidic direction in time.

The rocks of the Myao-Chanian intrusive series pierce or metamorphose the Upper Cretaceous extrusives of the Amutian series. At the same time the earliest rocks of the series — quartz gabbro and gabbro porphyry — have much in common with the pyroxene porphyry of the Amutian series in petrographic features, and this permits one to suppose that they may prove to be similar also in age relations. In this area, the upper age limit of the intrusive series represents too wide an interval (not younger than Neogene), but in the neighboring Kur-Urmiy area, according to the data of A.A. Golovneva, there are Paleocene extrusives unconformably covering intrusions similar to those of the Myao-Chanian series. Thus a Late Cretaceous age is very probable for the series, and this conclusion is well corroborated by the absolute age figures (Table 2, Figure 2). To the aforesaid it is possible to add that the Myao-Chanian series is in many respects, in places in great detail, very similar to the Upper Cretaceous, Bachelazian, intrusive series of central Sikhote-Alin' described in a special work [2].

It is evident from examining Table 2 that the age correlations between the studied specimens are confirmed by the argon method data. For specimens of porphyritic biotite-hornblende and corase-grained granite (Spec. Nos. 25-a and 34-b), however, it seems as if the argon method indicates a reverse age sequence, which contradicts geologic observations. The cause of this is not clear at present.

The above data concerning northern Sikhote-Alin' and the Myao-Chan Mountains testify to the presence in these areas of two intrusive

Table 2

Age of intrusive and extrusive rocks of the Myao-Chan Mountains

Sample Nos.	Name of rock	Sample location	K, %	$K^{40} \cdot 10^{-6}$ g/g	$Ar^{40} \cdot 10^{-7}$ g/g	$\frac{Ar^{40}}{K^{40}}$	Age in million years
24-d	Fine-grained granite	Chalbin massif	4.27	0.525	0.228	0.0043	75
34-b	Coarse-grained granite	Same			0.251	0.0053	95
			3.92	0.470	0.236	0.0050	88
25-a	Porphyritic biotite-hornblende granite	"			0.213	0.0047	83
			3.75	0.450	0.197	0.0044	77
41-a	Monzonite-granite	"	3.82	0.458	0.220	0.0048	84
61-c	Granite	Silin massif	4.01	0.482	0.255	0.0053	94
62-b	Monzonite-granodiorite	Same	2.60	0.312	0.168	0.0054	95
61-b	Gabbro porphyry	"	1.41	0.169	0.110	0.0065	113
32	Porphyry (from collection of Z. P. Potapova)	Trench 305 (Lake region)	1.56	0.187	0.128	0.0067	117

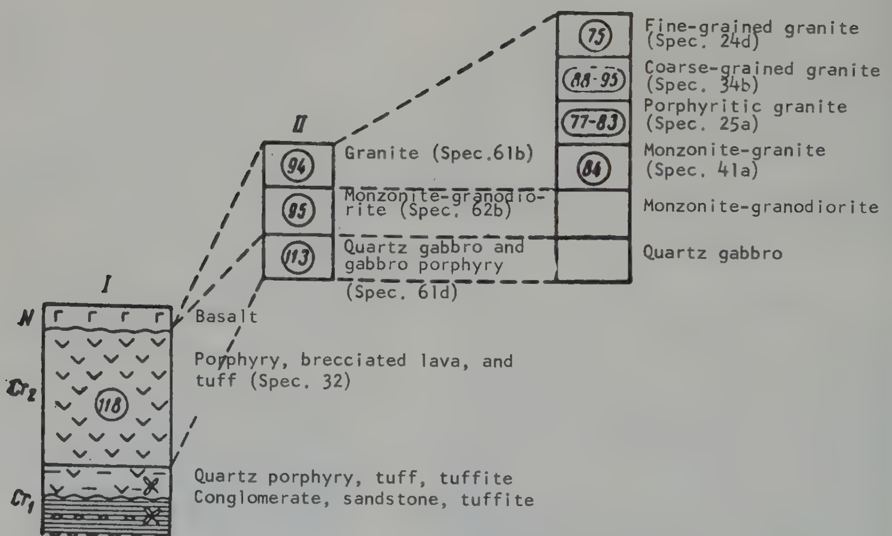

FIGURE 2. Scheme for the age sequence of extrusive and intrusive rocks of the Myao-Chan Mountains.

series of a similar type, one of which is undoubtedly Tertiary and has an absolute age of about 58 to 63 million years, while the other is Upper Cretaceous with an age of 75 to 113 million years. Both are very much alike in composition and sequence in which the intrusives were injected as well as in associated mineralization and ores. In many localities, especially in eastern areas of Sikhote-Alin', both series appear together and one does not always succeed in distinguishing them, even during special investigations. In this respect, it seems to us that determinations of absolute age may yield the most reliable results.

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LITHOLOGIC-TECTONIC COMPLEXES IN TERTIARY DEPOSITS OF SAKHALIN AND THEIR ASSOCIATED SEDIMENTARY MINERAL RESOURCES[1]

by

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The genesis of Tertiary deposits of Sakhalin are examined in this article. Three major rock complexes are distinguished, corresponding to definite stages in the tectonic development of the geosynclinal basin. The genesis of sedimentary mineral resources adapted to definite lithologic-tectonic complexes is clarified.

* * * * *

Much work devoted to investigations of the paragenetic associations of rocks has appeared lately in both Soviet and foreign literature [5, 8, 9, 11, 12]. The observed patterns in the variation of rock types constituting different structural elements of the crust, the grouping of rocks into definite complexes and the recurrence of these complexes are of great interest for the understanding of sedimentation processes.

Most research workers consider climate and tectonic conditions to be the main factors in the formation of such complexes. It is natural to suppose that the role of each of these factors in different structural units of the crust is not identical. The tectonic factor predominates in a geosynclinal environment, although climatic zoning leaves its mark on the emergence of one or another rock association.

In the history of any geosynclinal area, up to its conversion into a fold region, it is possible to note certain stages, distinguished by correlations between rates of sedimentation and tectonic movements, by the different morphology of the basin, by the different form of development and by the intensity of magmatic processes.

In each stage of development of a geosynclinal basin multi-phase, often intricately formed complexes of rocks are evolved, which we term lithologic-tectonic, since the material and environmental nature of these complexes is determined to a considerable extent by the tectonic development of the sedimentation basin.

We have attempted in this work to distinguish separate stages of sedimentation connected with the formation of the Sakhalin structure during the Tertiary period, and also to show the rock associations and their related minerals that are characteristic of a boreal geosynclinal basin situated in a humid climatic zone.

Sakhalin Island did not remain a uniform structural element during the Tertiary period. A large part of it should be treated as a geosynclinal region, having developed on a Mesozoic platform foundation, but the northeastern part should be attributed to the marginal zone of the young geosyncline of the Okhotsk Sea [7]. The northwestern part of the island (Langera district) and the mountain ranges along the east coast, composed of strongly metamorphosed Paleozoic rocks, belong to the platform and consolidated regions of ancient (Mesozoic) folding on Sakhalin.

In order to understand the geologic history of all Sakhalin it is necessary to examine the historical development of each of its constituent tectonic zones. Such zones include the southern part of the west coast, the eastern, central and northeastern regions and also the area of the Shmidt peninsula. We do not examine the Langera region situated in the northwestern part of the present territory of Sakhalin. A number of research workers quite rightly assume the presence here of a projection of the epi-Mesozoic platform.

It follows from the stratigraphic scheme (Table 1) that the recurrence of definite types of deposits, i.e., continental, littoral-marine, marine, persists, whereas the age of the strata changes somewhat.

Cretaceous and Paleozoic deposits were exposed at the surface as a result of folding which took place in the Maritime Region and Sakhalin

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[1]Litologo-tektonicheskiye kompleksy v Tretichnykh otlozheniyakh Sakhalina i svyazannyye s nimi osadochnyye poleznyye iskopayemyye.

Table 1

Schematic comparison of the Tertiary deposits in different regions of Sakhalin (after I.N. Kuzina, I.I. Ratnovskiy, S.N. Alekseychik, V.N. Shilov, L.V. Krishtafovich and the personal observations of the author)

Age		Western coast of southern regions of Sakhalin	Eastern coast and central regions of Sakhalin	Northeastern regions of Sakhalin	Shmidt Peninsula
		Series			
Pliocene		Maruyamian Marine shallow-water deposits	Maruyamian Marine shallow-water and fresh-water lacustrine deposits	Nutovian Marine shallow-water deposits	Matitukian Marine shallow-water and fresh-water lacustrine deposits
Miocene	Upper	Kurasiyan Relatively deep-water marine deposits	Kurasiyan Marine deposits	Okobykayan Marine and littoral marine deposits	Diatomic Marine deposits
Miocene	Middle	Uglegorskian Coal-bearing continental and lagoonal marine Nevel'skian marine and extrusive-sedimentary deposits	Uglegorskian Coal-bearing continental and lagoonal marine Nevel'skian marine deposits	Dagian Coal-bearing continental and lagoonal marine deposits, changing into marine deposits	Vengeriyan Marine deposits Cascadian Marine deposits
Miocene	Lower	Kholmskian Extrusive-sedimentary and normal marine deposits	Kholmskian Extrusive-sedimentary and normal marine deposits	Uynian Relatively deep-water marine deposits	Pil'sk Relatively deep-water marine deposits
Miocene	Lower		Khandasian Relatively deep-water marine deposits	Dayekhurian Relatively deep-water marine deposits	Tumian Relatively deep-water marine deposits
Miocene	Lower	Takaradayan and Arakayan Relatively deep-water marine deposits	Machigarian Littoral-marine deposits	?	Machigarian Littoral-marine deposits
Oligocene		Krasnopol'yevsk Littoral-marine deposits	Kuznetsovian Continental deposits		
Eocene		Lower Duysian Coal-bearing continental deposits Conglomeratic Continental deposits	?		

at the end of the Cretaceous period. Provided one does not count the Paleocene sediments of an obviously inland sea in the Sinegorsk region, a comparatively long period of sedimentation did not take place in this territory. During the Eocene the western part of the southern regions of the island started to subside, being expressed in the accumulation of thick beds of conglomerate. Next in the section are coal-bearing and littoral-marine deposits, corresponding to the Lower Duysian and Krasnopol'yevsk series, having a total thickness of 1200 m and found only in the southern regions of Sakhalin. It is difficult now to determine the western limits of the region of subsidence, since the boundary is hidden beneath the waters of the Sea of Japan. To the east, the basin was restricted by consolidated tracts, composed of Paleozoic and Cretaceous rocks and areas under erosion.

To the south, the region of subsidence extended as far as the island of Hokkaido, where continental and freshwater deposits, analogous in their conditions of formation to sediments of the Lower Duysian series, are known. In the north, the basin was limited by projections of the Mesozoic platform.

Subsequent developments of the basin were characterized by continued subsidence and by the expansion of the area of sedimentation. Comparatively well-sorted sandy-clayey deposits of the Takaradayan series, of an Oligocene - Lower Miocene age, have a considerably greater extent and reach a thickness of 1000 to 2000 m.

The subsidence enveloped the central part and eastern coast of the island. Sediments of a more shallow-water type, incorporated in the Machigarian series with a thickness of 850 m, were deposited here. The commencement of volcanic activity during the continued sinking of the basin is recorded in sediments of the Arakayan, Kholmskian and Nevel'skian series. In the northeastern part of Sakhalin, marine deposits of the Dayekhurian and Uynian series are spread over the marginal part of the Okhotsk Sea basin, persisting as evidence to the marine transgression of this time. The total thickness of deposits of the Kholmskian and Nevel'skian series of the southern districts of Sakhalin is 2550 m.

Shallow-water, marine conditions, alternating in places with continental conditions, were established throughout almost all Sakhalin in the Middle Miocene Coal-bearing deposits were laid down in a number of regions, changing along the strike into marine deposits. The thickness of this coal-bearing series ranges from 200 to 1200 m. Coal-bearing deposits of the Middle Miocene of southern districts of Sakhalin gradually change upwards in the section into relatively deep-water marine deposits of the Upper Miocene (Kurasiyan series). The West Sakhalin Range was formed as a result of folding at the boundary of the Upper Miocene and Pliocene.

Predominantly sandy rocks of the Pliocene were transgressively deposited on deposits of various ages in southern districts and attained thickness of 2500 m. The vulcanism of Pliocene time, during which layered deposits, di and more rarely tuffs, were formed, had a restricted extent. The composition of lavas ranged from basaltic to andesitic; dacites made their appearance. In southern districts the upper units of the Maruyamian series of Pliocene age compare well with the northern analogue of the Nutovian series. The basin was becoming shallow and was divided by ran composed of older rocks.

The geologic history of the Shmidt peninsula corresponds in general to the evolution of the southern districts, but it also has its own peculiarities. The coal-bearing deposits of Middle Miocene time are completely absent h being replaced by marine beds which graduall change upwards in the section into the deposit of a regressive basin. Just as in eastern districts of the southern half of Sakhalin, the old are the Machigarian series of the Lower Mioc

Detailed lithologic studies carried out by us for a number of years in various areas of Sakhalin have enabled us to distinguish definite sedimentary complexes, representing the morphologic peculiarities of geosynclinal basins in different stages of development.

The lower complex of continental, littoral marine and predominantly clastic rocks is composed of a rhythmically constructed series of beds, with a total thickness up to 2000 m.

The middle complex of largely marine, sedimentary and extrusive-sedimentary rocks consists of homogeneous argillaceous-siliceous and flysch beds, with a total thickness of 7000 m

The upper complex of predominantly arenaceous rocks consists of beds of a marine-mola type, with a thickness of 3000 m.

In southern districts of Sakhalin, deposits of the lower complex on the west coast belong to the Eocene to Oligocene interval and are revealed in a number of outcrops and boreholes i the Prisvodova part of the West Sakhalin Range The lowest member of the complex is a basal conglomerate, deposited transgressively and with angular unconformity on rocks of the Uppe Cretaceous which are distinguished by their greater degree of metamorphism. The conglomerates are interbedded with coarse-graine sandstones having coal-like seams in the upper part of the section. The conglomerate pebbles include rocks of Paleozoic and Cretaceous age, fragments of motley-colored jasper, quartzite and argillite and, much more rarely, fragment

of acid intrusive rocks not found on Sakhalin. The cement of the conglomerates is usually sandy, corresponding in composition to the pebbly material.

The source areas during deposition of this series were, apparently, the consolidated regions of ancient folding, already morphologically expressed at that time as positive elements of the topography, and parts of the Mesozoic platform of the Maritime Region, whence the acid intrusive rocks foreign to Sakhalin were supplied in the form of comparatively well-rounded pebbles.

The sandstone of the conglomerate bed is poorly-sorted and coarse-grained, commonly possessing inclusions of woody fragments and, in places, of petrified trunks of trees. The structural and textural properties of these rocks permit them to be assigned to the foothill facies, having been formed under conditions of continental sedimentation. Deposits of the conglomerate bed gradually change upwards in the section into coal-bearing deposits and then into littoral-marine deposits, characterized by a definite rhythm. The coal-bearing strata are represented by alternating sandstone, siltstone and clayey rocks with seams and bands of coal which in places are of workable thickness. The coal apparently accumulated in basins of a limnetic type. The rocks of the coal-bearing sections are distinguished by their poor sorting, and the sandstones have a gray-green color and are consertal in texture, with smears and lenses of clayey matter, while sandy and even gravelly bands are invariably present in the argillaceous varieties. Cross-bedding was observed in a number of cases.

Feldspars (plagioclase and microcline) usually predominate over quartz in the mineralogic composition of the sandstone. There is a large quantity of fragments of extrusive and siliceous rocks and grains of pyroxene, chlorite, glauconite, epidote, zircon, tourmaline and sphene. The cement of the sandstone is chloritic-clayey or carbonate-clayey, the carbonates in places being ferruginous.

Siltstones generally are blue or brown-gray. The composition of the terrigenous material is polymictic, analogous to that of the sandstone. Their cement is clayey carbonate or clayey chloritic. The clay minerals are a mixture of the hydromicas, kaolinite and beidellite. In their granulometric composition all varieties from sandy to clayey siltstones are present. In some varieties not one of the fractions comprises 50%.

The argillites are dark gray with a greenish or brown color, dense, and sometimes have a subconchoidal fracture. The clay matter consists of minerals of the montmorillonite group with admixed hydromicas and kaolinite. Silty material is present in negligible quantities in the form of very fine grains of quartz, feldspar and pyroxenes.

The rhythmically constructed coal-bearing series of Eocene age is gradually replaced by littoral marine deposits of the Lower Oligocene. The sedimentary rhythm in the lower part of this series commences with a band of conglomerates with comparatively well-rounded pebbles of predominantly Cretaceous and Paleozoic rocks. A characteristic feature is the spatial position of flat pebbles oriented parallel to the rock stratification. Oysters often occur in the conglomerate, oriented parallel to each other and to the rock stratification. Their shells are complete with a well-preserved sculpture.

The second member of the rhythm consists of medium- and fine-grained sandstone with admixed clayey matter and inclusions of pebbles of extrusive and siliceous rocks. Above are siltstones with sandy inclusions, over which conglomerates with oysters were again deposited. Traces of wave-cut ripples are sometimes seen on the bedding surfaces of the sandstone. The degree of rock sorting increases markedly upwards in the section. Thin seams of coal occur in a number of sections. The accumulation of sediments took place under constantly changing marine and continental conditions, with a general tendency for the whole region towards subsidence. L. V. Krishtofovich describes faunal complexes in deposits of this age which indicate a normal marine basin of shallow depth with water of relatively high temperature.

According to petrographic composition, the rocks deposited under littoral marine conditions are very similar to the rocks of the continental facies described above. The sandstones are unevenly-grained and polymictic, commonly containing separate inclusions of pebbles of siliceous and argillaceous rocks with smears and lenses of clayey matter. A characteristic feature is the inclined and convergent bedding. Strongly carbonate varieties are present. The cement is mostly clayey-chloritic, in places with admixed carbonate matter. The chlorite is authigenic and newly-formed, and is developed in clayey-siliceous matter. Hydromicas and kaolinite are the predominant clay minerals of the siltstone and argillite. Terrigenous material is characterized by the presence of feldspar, quartz and pyroxene. Gritty grains of siliceous and argillaceous rocks and smears of clayey matter are almost invariably present as inclusions.

On the whole, this complex of deposits corresponds to the initial stage of formation of the basin; it is distinguished by the coarse grain of the rocks, by their poor grading, by the presence of coal seams and by the rhythm.

The composition of the terrigenous material

for the whole complex is more or less alike. A characteristic feature is the predominance of feldspar over quartz in light fractions and the appreciable quantity of fragments of extrusive and siliceous rocks, often comprising up to 40% of the rock. Epidote, pyroxene, tourmaline, sphene, zircon and chlorite are present in heavy fractions. Post-sedimentation changes, it is true, depended mainly on the environmental conditions, nevertheless it is also possible to outline some general features of the complex as a whole, since only the carbonates of calcium and iron participate in the composition of the concretions, $FeCO_3$ gravitating to coal-bearing strata and $CaCO_3$ to marine strata. $MgCO_3$ was not found in the consistency of concretion. Amongst the cements, apart from clayey, kaolinitic hydromicaceous and beidellitic matter, ferruginous chlorite and calcite are of considerable importance; glauconite is comparatively rarely detected.

There is no abrupt boundary between the deposits of the complex described above and those of the next complex, representing the stage of maximum submergence in the basin. As early as the Middle Oligocene, however, the size of the basin was considerably increased, the area occupied by Oligocene and Miocene deposits had spread further to the north and east, and, above all, the morphology of the bottom was changed: a level, shallow reservoir was converted into a relatively deep-water basin with a comparatively small zone of turdidity. The bottom of the basin sagged intensely, the rate of sagging evidently having predominated over the rate of sedimentation; shallow-water, coarse-grained sediments were replaced by argillaceous-siliceous deposits of the Oligocene and Lower Miocene, enriched by volcanic material to a considerable degree.

The structural and textural peculiarities of rocks of the lower part of this complex, and also the faunal remains, testify to relatively deep-water sedimentation conditions. Clayey and silty varieties, moderately- and well-graded and containing numerous faunal remains, predominate. Higher in the section volcanic rocks are of much greater importance; coarsely fragmental varieties representing the decomposition products of the volcanic formations also occur in this section.

According to V. N. Shilov [10], volcanic rocks of the Lower Miocene are pyroxene andesite and dacite, as well as porphyries and tuffs of the same composition; olivine-augite and augite basalts, porphyries and tuffs were developed in the Middle Miocene.

The dispersion of volcanic material around the volcanic structures caused a sudden environmental change in the rocks of this complex. The appreciable tectonic activity during this stage of development of the geosynclinal basin, the irregular inflow of pyroclastic material and, apparently, the unsettled hydrologic conditions caused the accumulation of flysch-like fragmental strata, in which tuffaceous rocks are of great importance. The flysch in places has a dual structure, with alternations of thin sandy and clayey varieties. Lenses and seams of coal, interbedded with tuff, occur in places in volcanic deposits of the Middle Miocene, while comparatively thick coal-bearing beds accumulated at the end of the Middle and beginning of the Late Miocene. The accumulation of coal-bearing strata in the period of dying (but still incompletely suspended) processes of vulcanism conditioned the complex environmental relationships between the marine, extrusive-sedimentary and freshwater-continental deposits. The reservoirs of accumulation of peat bogs, the source of the coals, were formed during the continuous struggle of land and sea, as indicated by seams with a marine fauna and by the genetic types of rocks constituting the coal-bearing series. According to B. A. Sal'nikov [6], fluvial, deltaic and estuarine deposits have been detected. Seams of bentonitic clay or argillite with an appreciable content of clay minerals of the montmorillonite group are persistent members of the coal-bearing deposits. In thin sections one sometimes manages to see montmorrillonite developed in volcanic glass.

Epeirogenic movements, which enveloped a large area, evidently had a substantial role in the formation of coal-bearing beds during the geosynclinal stage of development of the basin.

The accumulation of coal-bearing beds or deposits of relatively shallow-water environments took place at this time over much of the territory of Sakhalin and Japan. Moreover, the abundant inflow of volcanic material, which quickly filled the basin, was of great importance in a number of regions, and this led to uncompensated sedimentation, i. e., shoaling.

Upwards in the section coal-bearing deposits were gradually replaced by relatively deep-water, homogeneous, fine-grained, siliceous sediments.

Beds of mold and diatomite or of siliceous, clayey, mold-like sediments are characterized by insignificant amounts of terrigenous material that is very well graded. In most varieties, the main rock-forming elements were diatoms, whose siliceous valves were almost completely dissolved by subsequent processes of diagenesis and were only preserved in numerous carbonate concretions. Evidently, the cessation of extrusive activity and the peneplaned nature of the surrounding land at the end of Miocene time conditioned the small inflow of clastic material into the basin. Post-Umanian developments of vulcanism could have been the source of the abundant inflow of silica into the basin.

In this short article it is impossible to describe all the rock types in the described complex, and we will only dwell on those that are most abundant.

Fine- and medium-grained varieties of sandstone predominate in the marine deposits of the interval studied. The composition of sandstone is usually polymict, and feldspars (plagioclase, microcline), quartz with a mosaic texture and wavy extinction, garnet, zircon, chlorite, biotite, epidote and large quantities of fragments of extrusive- and siliceous-rock fragments are present.

In accordance with the location of the area where the sandstones occur, their mineralogic composition is somewhat variable. The content of feldspars reaches 20 to 30% and, as a rule, exceeds the amount of quartz. The material is for the most part well graded. Thinly- and horizontally-bedded sandstones occur side by side with irregularly bedded or even massive varieties. The sandstones have a clayey and clayey carbonate cement.

Glauconitic sandstones, which are more accurately termed glauconites, are very abundant. They are sandy-clayey rocks wherein the sandy fraction consists almost exclusively of authigenous grains immersed in a sandy-clayey mass.

In marine formations, the siltstones are subdivided into two main types.

The siltstones of the first type, occurring mainly in the lowest parts of the complex, are gray or yellow-gray, are unstratified and lumpy and contain a large amount of chaotically-dispersed pebbles of siliceous, extrusive and clayey rocks, with dimensions of 1 to 2 cm. On weathering the siltstones acquire a splintery form and become highly ferruginous. Considerable quantities of plant detritus and faunal remains are present. The sandy fraction comprises 20 to 30% and consists of grains of quartz, plagioclase, microcline, epidote, chlorite, etc. The clay fraction comprises 10 to 12% in all. The clayey material is a mixture of hydromicas and kaolinite.

Siltstones of the second type are present in volcanic deposits and in the upper part of the complex. Their color is blue-gray, becoming more intense on weathering. The fracture is subconchoidal and the rock is usually very dense. Clayey siliceous matter amounts to 40 to 45%. Apart from hydromica, opal is present in large quantities. The silty material consists of grains of quartz, plagioclase, biotite, chlorite, pyroxene and glauconite. The SiO_2 content in some varieties amounts to 15 to 20%.

In the very widespread argillite, it is also possible to discern more sandy and more siliceous varieties.

Sandy argillites have a dark-gray or greenish-gray color; they are dense, lumpy, with an obscurely-bedded texture, and give a shelly and platy parting on weathering; clayey matter comprises from 60 to 80% and displays a yellowish-gray tint in transmitted light under the microscope; it is composed mainly of minerals of the hydromica and beidellite groups; opal is present. The siltsand fraction is composed of quartz, feldspars, epidote, chlorite, zircon, garnet and pyrite. The material is relatively well graded. Phosphate-bearing varieties of argillite are present, the seams having a thickness of 0.3 to 0.5 m and a lenticular occurrence. Their P_2O_5 content ranges from 1.5 to 7.5%.

Argillites occurring in extrusive-sedimentary formations and also those that are widespread in upper parts of the complex are distinguished by their siliceous nature. They are dense, generally bluish-gray rocks, in places with a subconchoidal fracture; their color becomes considerably lighter on weathering. Both stratified and non-stratified varieties are observed. The homogeneous (non-stratified) argillites are finely dispersed, their pelitic fraction comprising 85%. The terrigenous material, with an average diameter of 0.004 mm, is usually well graded and embodies feldspars and quartz; glauconite of a visibly authigenic origin occurs in places. Silica is present in the form of opal, its content amounting to 20 to 30%.

The heterogeneous (stratified) argillites have a thin (up to 0.05 km), horizontal and continuous or discontinuous stratification. Very thin seams of siliceous matter alternate with coarser particles of terrigenous and, in places, volcanic material. The pelitic fraction constitutes from 60 to 70% of the rock. The terrigenous matter consists of feldspars, quartz, pyroxene, chlorite, biotite and glauconite. The material is less well graded than is the non-stratified argillite. Some separate lenses, with lengths of up to 2.5 m, are phosphatized, the $CaCO_3$ content also rising in these lenses.

Molds and diatomite occur mainly in upper parts of the complex where various transitions exist between siliceous argillite, mold-like rocks and molds. Typical molds are light gray or yellowish gray, have a low specific gravity and "adhere" readily. In thin section under the microscope it is seen that the main mass is clayey siliceous isotropic matter with a gray-yellow color. It is sometimes possible to discern sponge spicules and poorly preserved remains of radiolaria and diatoms.

Terrigenous material, which is present in small amounts, consists of grains of silty varieties of feldspar, quartz, pyroxenes and

rock fragments. The terrigenous material is in places poorly graded. One manages to make out the preserved remains of volcanic glasses. According to the chemical analyses, the content of amorphous SiO_2 ranges from 40 to 75%.

Seams of opaline clay of the "marshallite" type, with a thickness of 1.5 to 2 m, sometimes occur in the bed of mold and mold-like rocks. Opal in the form of very small spheroidal grains constitutes the bulk of the matter in these clays. Terrigenous material is almost completely absent.

Comparatively widely-developed bentonite clays, deposited in beds up to 2.5 m thick, usually are bluish gray or light gray. The clays are highly dispersed and soft, and on drying they become lighter and break down into slabs with a conchoidal fracture. According to M.A. Zakharova [4], the terrigenous material amounts to 10 to 12%, $CaCO_3$ reaching 20 to 30%. A feature is the somewhat low Al_2O_3 content of 15% and the high hygroscopic-water content of 19.5%. The main mineral in this type of clay is montmorillonite with $\gamma c^P = 1.538$. The montmorillonitic nature of the clay matter is corroborated by thermal and X-ray analyses.

We have already noted that vulcanism, having supplied a large quantity of pyroclastic material to the sedimentation basin, influenced the course of sediment formation and created a large number of different types of extrusive sedimentary rocks. Within this article we will dwell only on the character of the main rock types enriched by pyroclastic material.

Pyroclastic material near the volcanic centers has the greatest size. Beds of volcanic breccias and conglomeratic breccias are developed, composed of both the disintegration products of volcanic structures and the actual materials from volcanic ejections. The size of fragments and partially-rolled pebbles varied greatly, attaining 1 to 1.5 m in diameter.

The coarsely fragmental volcanic rocks are cemented by material of similar composition, but with smaller dimensions and commonly with admixed volcanic glass. Stratification is present, conditioned by the alternation of bands of coarse and fine material. The thickness of these beds increases in the direction of the volcanic centers and reaches 1000 m. The phyroclastic material also decreases both in size and amount according to the distance from these centers upwards in the sections. The tuffaceous rocks have a different granulometric composition: tuffaceous sandstone, siltstone and argillite are distinguished, these in turn being subdivided according to the amount of terrigenous, non-pyroclastic material they contain. In addition, one should distinguish tuffs proper, composed of almost 100% pyroclastic, generally ungraded material. Tuffaceous, coarse- and medium-grained sandstone, with a greenish-gray, rose or black color, are widespread and correspond in petrographic composition to coarsely fragmental, volcanic rocks. The cement of the sandstone is clayey, clayey chloritic and in places slightly calcareous. The terrigenous and pyroclastic material is slightly rounded and comparatively poorly graded. Besides numerous fragments of extrusives, volcanic glass and microlitic feldspars, there are fragments of plagioclase and siliceous rocks and grains of epidote, garnet, magnetite and occasionally glauconite.

In thin section under the microscope, the tuffaceous siltstone is a siliceous-clayey mass, usually yellowish-brown, and feebly birifringent because of pointed inclusions of feldspars and quartz. Volcanic and terrigenous material of silt dimensions is immersed in the matrix and consists of leist-shaped needles of plagioclase and fragments of extrusive rocks and quartz. One sometimes succeeds in discerning the remains of diatoms.

Tuffs are widespread in the rocks of the described complex. Many of them are lithoclastic varieties and have often been mistaken by other research workers for arenaceous rocks of the graywacke type.

Fragments of volcanic rocks (andesite with an insertal and hyalopilitc texture or basalt) are seen under the microscope. The fragments are usually of an irregular, acute-angled form, and are strongly decomposed, partially chloritized and cemented by carbonate, zeolitic, or chloritic material of the contact type. In places, it is possible to distinguish crystalline lithoclastic tuffs, differing from lithoclastic tuffs in the presence of crystals of basic plagioclase in addition to extrusive fragments.

The vitroclastic and vitro-crystalloclastic tuffs occur in small layers and are rather dense rocks of a light and occasionally rose color. They consist mainly of strongly altered, chloritized glass of basic composition.

Microlites of plagioclase are distinguishable in the glass, secretions of acicular crystals of zeolite being seen in individual places. Comparatively coarse crystals of plagioclase and their fragments are immersed in the matrix. Pyroxene and magnetite crystals and small fragments of extrusives are present.

Amongst rocks of the described complex, apart from deposits of marine genesis, one encounters rocks of the continental, lagoonal and littoral marine facies in the coal-bearing series of the Upper Miocene. Conglomerate, gravel and coarse-grained sandstone, belonging to the alluvial cycle, are distinguishable. They are composed of angular and rounded rock fragments of corresponding varieties. Fragments of siliceous rocks, siltstone, argillite, quartz

igneous rocks are present; the cement clayey-silty sand.

The sandstones are medium- and fine-grained, light gray and dark color, friable and com- t (originating in the environment of deltas, s, seepages, bars, etc.), homogeneous and ss-bedded. Inclusions of small pebbles, rtz, argillite and sandstone are seen. The l seams are of a workable thickness.

The siltstones are coarse- and fine-grained ginating in the environment of bottom-lands, es, gulfs, lagoons, etc.), of a dark gray brown color, rubbly or with a shelly parting, ked with coal seams, homogeneous and thinly ded, sandy and comparatively poorly-graded. e bedding is wavy, more rarely horizontal.

The argillites are silty and muddy (originat- the environment of swamps, lakes and oons), gray, brown, almost black and oc- sionally carbonaceous or with seams of coal.

The clays are argillitic, of a dark-gray color, hly dispersed, soft and have a high P_2O_5 ntent. Bentonitic clays are present.

The coal bearing deposits carry indications, culiar to the remaining members of the com- x, of the maximum sagging stage of the basin. replacement of coal-bearing deposits by ex- usive-sedimentary deposits is observed. der these conditions of comparatively slow dimentation, the pyroclastic material was e source of the bentonitic clays.

Individual seams of clayey or sandy rocks e enriched by glauconite.

The types of rocks enumerated form an ricate paragenetic complex in which it is ssible to distinguish the following strata: flysch, composed of thin alternations of lcanic sandstone, siltstone, argillite, tuff d tuffite; sometin es only two varieties, ually enriched by volcanic material, are ely interbedded; 2) sandy-clayey strata, nsisting of interbedded packs of sandy and lty argillitic rocks, 200 to 400 m thick; 3) ayey siliceous strata, generally homogeneous, aching a great thickness and consisting of ltstone or mold-like rocks; 4) coal-bearing rata with a cyclic structure.

In the described complex of deposits cor- esponding to the stage of maximum sagging of e south Sakhalin area, it is possible on the hole to note the following characteristic eatures: terrigenous rocks of the complex are omparatively well-graded, and fine-grained arieties of argillite and fine-grained sand- tone predominate. Different types of volcanic ormations, enriched by pyroclastic material a varying degree, are widespread, as are eir siliceous varieties; glauconite and bentonitic clay are constantly present in the deposits of this complex; the mineralogic composition of the rocks is variable, but, in comparison with the lower complex, an increase of such stable minerals as garnet, zircon, apatite and sphene is generally noted. Feldspars continue to predominate over quartz in the light fraction, although an inverse relationship has been noted in the upper part of the complex. Minerals of the montmorillonite group are very abundant amongst the clay minerals in addition to hydromica and kaolinite. The amount of rubble in the mineralogic composition of the rocks remains high. Their provenance was principally situated to the northeast. Evidently, Paleozoic ranges were being eroded. Post-sedimentation changes differ somewhat from those in rocks of the lower complex. The cement of the sandstone is predominantly clayey and micaceous, and occasionally zeolitic. Authigenic glauconite is widespread. Together with $CaCO_3$ and $FeCO_3$, $MgCO_3$ are also important in the composition of the concretions.

The closing stage of development of the geosynclinal basin in the southern part of the island took place in Pliocene time during the formation of the intricately constructed anticlinorium of the West Sakhalin Range and during the dismemberment of a previously single basin of sedimentation.

Patterns in the changing thickness and lithology of the sediments of Pliocene age speak with confidence of the existence of two basins isolated from each other and situated to the east and west of the dividing West Sakhalin Range. We have incorporated the sediments of these basins into a single lithologic-tectonic complex of predominantly arenaceous rocks (sands and sandstones), composed of strata of a marine molasse type. Together with sandy polymictic varieties, small bands of glauconitic sandstone, clay and conglomerate and pebble beds are involved in the structure of this complex. Lignites, transformed in a few places into soft brown coal of an unworkable thickness, are present at the very top of the complex.

The sands are usually of light tints and are very weakly cemented by clayey material; all granulometric varieties, from coarse- to fine-grained sand, are present. According to L.S. Zhidkova, quartzose, feldspathic and polymictic varieties are distinguishable in the mineralogic composition of these sands. As a rule, the amount of quartz predominates over that of feldspar; epidote, hornblende, ilmenite, zircon, apatite and biotite are also present.

Conglomerates in the form of bands have an average number of comparatively well-rounded pebbles 4 to 5 cm in size. Jasper, quartzite and chlorite-sericite rocks are distinguishable in the mineralogic composition of these pebbles; pebbles of sedimentary rocks like argillite and

and sandstone, and pebbles of volcanic rocks, predominate in some regions.

The clays are usually dark, poorly-graded varieties; seams of lignite sometimes occur in them. Clay minerals of the hydromica group predominate, kaolinite being rarer.

Characteristic features of all rocks of this complex are their poor grading and great environmental variability. Certain variations are noted in their mineralogic composition; thus, quartz predominates over feldspar in the light fraction, while the chief minerals of the heavy fraction are epidote, hornblende, ilmenite, sporadic garnet, sphene, sillimanite, apatite, kyanite and occasionally glauconite.

In the western basin, on the west coast of the southern part of the island, volcanic rocks in the form of basalt deposits are also noted.

Analogous lithologic-tectonic complexes, corresponding to different stages of development of a geosynclinal basin, are distinguishable in the section of Tertiary deposits of the Shmidt Peninsula, in the northern part of Sakhalin.

The geologic development of the Shmidt Peninsula during Tertiary time can be depicted in the following sequence: the formation of a geosynclinal basin on a basement platform of apparently Mesozoic age began at the end of the Oligocene and was accompanied by the accumulation of littoral marine and lagoonal sediments; then the deposition of normal marine sediments and extrusive-sedimentary beds occurred, enriched by siliceous material to a considerable degree. Intense vulcanism and outpourings of basalt lava occurred in the second half of the Early Miocene. The period of maximum sagging of the basin and the accumulation of fine-grained siliceous sediments occurred in Middle Miocene time.

Uncompensated sagging of the basin was replaced by uncompensated sedimentation at the end of the Middle and beginning of the Late Miocene, which was reflected in the gradual shallowing of the basin.

Littoral, shallow-water and lagoonal conditions, leading to the accumulation of lignite, as in the south, prevailed in Pliocene time on the peninsula. The total thickness of all complexes amounts to around 8000 m.

A section of Tertiary deposits in the northeastern part of Sakhalin, well known at the present time, begins with deposits that are regarded as being of an Oligocene - Lower Miocene age. They are marine, clayey-silty and more rarely sandy rocks, enriched to a low degree by volcanic material. In the deposits of the Middle Miocene the flintiness of the rocks increases and their sandiness decreases.

At the end of the Middle Miocene, just as in southern districts of Sakhalin, one notes the general coarsening of the sediments, the increasing role of arenaceous formations and the transition in a southerly direction from marine environments to littoral marine and even continental environments possessing coal seams of workable thickness. These beds were graduall replaced by silty-clayey deposits, which are distinguished from similarly-aged sediments prevailing in southern districts of Sakhalin by their much less siliceous nature and by the presence of sandy material. The complex of rocks timed to the stage of maximum sagging in the basin ended, evidently, with deposits of this type, because it is succeeded by a sandy gravelly series, up to 2500 m thick, which is completely comparable with deposits of the closing stage of development of the geosynclinal basin in southern districts of Sakhalin and the Shmidt Peninsula.

The sedimentation in the above-described basins has a number of similar features, but it also possesses specific characteristics peculiar to each of the investigated regions (Figure 1).

Thus, the presence of coal-bearing deposits of a limnetic type characterizes the lithologic-tectonic complex of the initial stage of development of the geosynclinal basin in southern Sakhalin. These latter deposits, apparently, are consistent members of this complex under humid conditions of sedimentation. An equally characteristic formation is the conglomerate bed occurring at the base of the complex.

Both conglomeratic and coal-bearing rocks, however, are absent at the base of Tertiary deposits in the northeastern part of Sakhalin, where, judging from the deep borehole at the town of Okha, marine deposits of the Oligocene-Lower Miocene lie directly on faulted rocks of the Upper Cretaceous. This is, apparently, explained by the fact that the given case refers to marginal parts of the geosynclinal region, whereas the lithologic-tectonic complex of the initial stage of development of the basin had a limited areal extent and did not occupy these marginal regions.

There are rather substantial differences in the composition of the second lithologic-tectonic complex of southern and northeastern districts of the island and also of the Shmidt Peninsula. Marine, fragmental, extrusive sedimentary and siliceous rocks characterize all these regions in this stage of their tectonic development, although pyroclastic material is considerably more common in the succession in southern regions of Sakhalin, and a rather thick series of coal-bearing sediments is present.

In the northeastern part of the island coal-bearing deposits occur only along the periphery

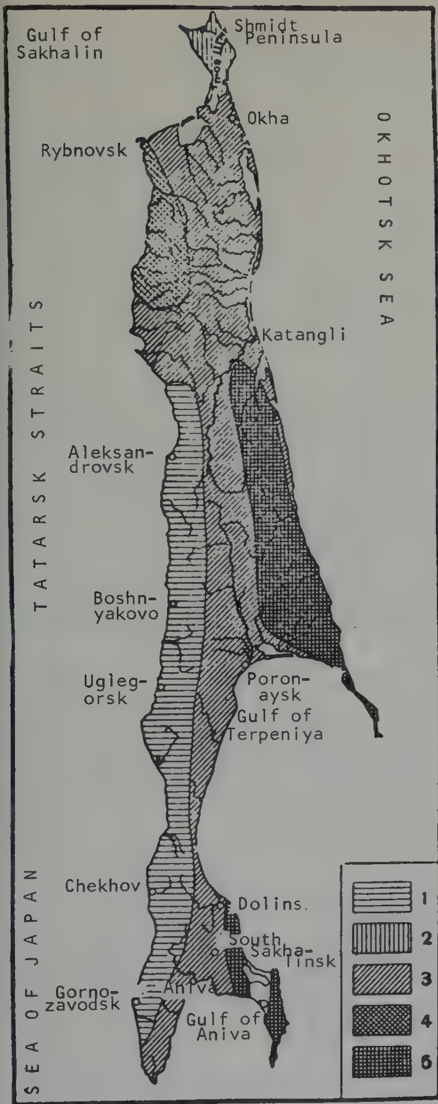

FIGURE 1. The distribution of lithologic-tectonic complexes of Tertiary deposits on Sakhalin Island.

1 - development area of the lower, middle and upper complexes; 2 - development area of incomplete lower, middle and upper complexes; 3 - development area of the middle and upper complexes; 4 - area of platform conditions of sedimentation in Tertiary time; 5 - ancient, folded, consolidated regions.

of the region of sagging; they evidently represent a transitional type between platform and geosynclinal deposits.

In southern districts the presence of coal-bearing deposits in rocks of the second complex was not controlled by general patterns of development of individual geosynclinal basins, the subsidence of separate blocks and epeirogenic movements, which covered an extremely large area and which led to the general regression of the sea and the temporary shallowing of the basin, against a background of continued sagging of the geosynclinal region. The development of these latter deposits did not take place uniformly, and, from the character of the deposits, it is possible to designate two possible correlations between the rates of sagging and sedimentation in the basin.

In the first case, when the rate of sagging exceeded that of sedimentation in the basin, a gradual change upwards in the section from shallow-water to more deep-water sediments developed. Such correlations occur in all three regions of Sakhalin we have described, for the first lithologic-tectonic complex and for the first half of the second complex, up to the time of active development of volcanism.

The intense inflow of volcanic material created an inverse correlation between the rates of sagging in the basin and the inflow of fragmental material, which led to the regular change of rocks upwards in the section from deep-water to shallow-water types. This relationship is most clearly displayed in the Shmidt Peninsula, where, starting in the Middle Miocene, sediments became more and more arenaceous and were replaced in the Pliocene by deposits of peaty lagoons.

Volcanic activity greatly influenced the sedimentation processes. Lenses of extrusive-sedimentary rocks, concentrated near the separate volcanic foci and substantially changing the environmental appearance of similarly-aged sedimentary formations, were formed. Our structural study of these lenses shows that they are composed largely of coarse agglomeratic rocks and different litho-crystalline tuffs and tuffaceous rocks. The vitroclastic tuffs have usually been moved for considerable distances from volcanic centers, as is also the case with the fine siliceous rocks. The formation of these siliceous rocks is evidently related to post-Umian volcanic activity, as a result of which the sea water was enriched by silica. Little terrigenous material was introduced. The precipitation of SiO_2 evidently took place mainly by a biogenic method.

Sedimentary minerals occur in definite complexes, and although some of them are also encountered in all three complexes, the conditions of their formation, however, changed in relation to the stage of development of the basin (Table 2).

We have already noted that although coal may be present in deposits of all three stages of the geosynclinal basin, the type of coal accumulation changed. Coal of a predominantly limnetic type was formed in the initial stage. Any

Table 2

Lithologic-tectonic complexes in Tertiary deposits of Sakhalin and their associated mineral resources

Age		Types of deposits	Thickness (m)	Main types of sections	Lithologic-tectonic complex	Sedimentary mineral resources
Pliocene		Marine shallow-water deposits of intermontane depressions changing vertically into deposits of fresh-water reservoirs.	2000--2500	Poorly-graded, predominantly sandy sediments with bands of conglomerate and lignite, deposited transgressively on different series.	Upper	Lignite, phosphorite
	Upper	Marine siliceous, relatively deep-water deposits.	700-1700	Homogeneous beds of clayey rocks enriched by silica.	Middle	Coals, siderite, bentonitic clay
	Middle	Coal-bearing deposits of paralic basins; Volcanic-sedimentary deposits	200-1500	Interbedded sandy and clayey rocks with coal and coaly argillite, replaced environmentally by volcanic-sedimentary or normal marine deposits.		Phospherite
		Littoral marine deposits; Volcanic-sedimentary deposits	1900	Thin alternations of sandy and clayey r rocks, enriched by volcanic material, changing environmentally into volcanic-sedimentary deposits.		Glauconite
	Lower	Marine relatively deep-water deposits	2200	Clayey rocks, enriched by silica, with layers of volcanic rocks, changing environmentally into volcanic-sedimentary deposits; frequent seams of glauconite.		
Oligocene		Volcanic-sedimentary deposits. Marine, relatively deep-water deposits.	1000	Sandy-clayey beds with bands of glauconitic sandstone, changing environmentally into volcanic-sedimentary deposits.		
Eocene		Littoral marine deposits. Coal-bearing deposits of limnetic basins.	850	Poorly-graded rocks, corasely fragmental material present as inclusions, bands and beds; carbonaceous argillite and and coal of a workable thickness.	Lower	Phosphorite, coal, siderite
		Continental deposits of intermontane depressions.	600			

accumulation of coals of the paralic type may have occurred at the very end of this stage. On the contrary, the same type of coal may not have formed during the stage of maximum sagging of the basin: the coal formed was the type that accumulated in paralic reservoirs. Coals were again formed in freshwater, lacustrine conditions in the concluding stage, but the scale of coal accumulation was small, and owing to the negligible degree of metamorphism these coals are of low grade.

The comparatively recent discoveries of phosphorites of Sakhalin are also encountered in all three lithologic-tectonic complexes. The main deposit [1], as well as the comparatively high phosphatization of rocks, is noted in the stage of maximum sagging of the basin. A deposit of this type is situated on the west coast of the Shmidt Peninsula and occurs in clayey siliceous formations of the Pil'sk series of Middle Miocene age. Seams of clayey siliceous rocks enriched by authigenic glauconite are present. Numerous phosphorite nodules, whose phosphorous content reaches 36%, occur at the base of these seams.

A high organic carbon content characterizes every phosphorous-bearing sheaf. A study of the lithology, geochemistry and fossil remains of the sediments permits a conclusion to be drawn about the relatively deep-water environments to which phosphate formation is adapted.

The wide development of a diatom flora, discovered in phosphorite and not preserved in the enclosing siliceous rocks, indicates that the phosphate dissolved by water might have been picked up and transferred by plant plankton to the slime where the following processes of diagenesis led to the formation of phosphorite nodules.

The formation of phosporite went on in the slime until the slime solidified, because a squeezing out of siliceous matter and glauconite is observed at the contact of the phosphorite with the cementing rock. The following sequence in the development of authigenic minerals during phosphate formation becomes clear: amorphous phosphate - glauconite - chlorite - siderite - pyrite - crystalline phosphate - chalcedony.

An indispensable condition of phosphate formation was the negligible inflow into the reservoir of terrigenous material, which would have lowered the concentration of phosphate in the sediment. Post-Umanian volcanic activity possibly favored the enrichment of sea water by silica and phosphorous.

A comparatively high phosphatization of siliceous clayey deposits of the same stage of maximum sagging of the basin accured in southern districts of Sakhalin. In certain regions siliceous clayey rocks of a Middle Miocene age contain up to 4 or 5% P_2O_5. Carbonate concretions occurring in relatively deep-water deposits of the Miocene and uppermost parts of the Oligocene are commonly enriched by P_2O_5 to 7 or 9.5%, whereupon the P_2O_5 content in the concretionary seams remains constant. An elevated phosphorous content is observed in marine facies of the coal-bearing deposits of the described complex and testifies to the general contamination of the basin by phosphorous.

Phosphorites of another type occur in deposits of the concluding stage of development of the geosynclinal basin. Phosphorites of Pliocene age in the bed of the Daga River (Northeastern Sakhalin), described by N. D. Tsitenko [3] and by us, occur in a stratum of poorly-graded sand and sandstone, and are both lenses in a consertal, polymictic sandstone with a phosphatic-chloritic cement and clayey sandy concretions with a ferruginous cement.

Phosphatized clay with a P_2O_5 content up to 14 or 15% envelops the inner part of the concretion, consisting of a coarse-grained, very poorly-graded sandstone, like a coating. Phosphatized clayey bands, analogous in composition to the clayey coating on the described concretions, have been discovered. One should assume that, in the shallow-water zone of perpetual agitation where the phosphorites were formed, fine clayey particles were washed out of the sediment and immediately deposited again around the sandy nucleus. Phosphorous might have come in from dry land as an erosion product of ancient strata and then adsorbed by clayey suspensions. There are indications of the high content of phosphorous in Paleozoic and Cretaceous rocks, which were one of the sources of clastic material for these basins in the closing stage of their development.

Phosphorites adapted to the initial stage of development of the basin have been discovered on the west coast of the southern part of Sakhalin; they are tapering seams of a phosphatized, clayey-carbonate rock occurring in deposits of a littoral marine origin. Conglomerate, oyster beds and sandstone with smears of clayey material and coaly inclusions alternate with beds of siltstone and argillite containing thin coal seams.

During the repeated replacement of continental by marine conditions, which took place during the period of formation of the stratum, phosphorous, having accumulated with iron in waters of low-lying peat bogs, might have been precipitated under alkaline marine conditions and enriched the clayey sediments.

Bentonitic clays occur mainly in deposits of the stage of maximum sagging of the basin, where they are associated with coal-bearing deposits of Miocene age.

The coal accumulation of Miocene time took place with the assistance of considerable quantities of pyroclastic material; processes of the decomposition of volcanic glasses and feldspars, which took place, led to the formation of comparatively homogeneous beds of bentonitic clay. Thin seams of bentonitic clay were also formed in the marine clayey siliceous strata.

Siderite concretions are also associated with coal-bearing rocks and form numerous seams in deposits of the lower complex, both in the initial stage of formation of the basin and in the stage of its maximum sagging. As recent investigations [2] have shown, the formation of numerous siderite concretions took place during sedimentary diagenesis as a result of the redistribution of matter and did not require appreciable quantities of iron in the enclosing strata. Apart from $CaCO_3$ and $FeCO_3$, $MgCO_3$ is also present in the siderite complex of the stage of maximum sagging, reaching 14%.

Molds, diatomite and mold-like argillite occur only in deposits of the stage of maximum sagging of these basins. They are usually rocks of light, yellowish and bluish tints, becoming still lighter on weathering. The content of amorphous SiO_2 reaches 60%. The terrigenous material, with mean dimensions of 0.004 mm, is usually very well-graded and consists of feldspars and quartz; glauconite is sometimes present.

Numerous tests of diatoms are clearly seen in the diatomite, but in the molds and mold-like argillite, diatom algae and radiolaria are preserved only in carbonate concretions. These concretions are constantly present in these beds, have a dolomitic composition and in places consist entirely of dolomitized organic remains. The transition between various types of siliceous rocks is gradual. On the whole the southern regions of the island are distinguished by the more siliceous nature of their rocks than in the northern regions.

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CONCRETIONS IN THE AKTOPRAK SECTION ON CHEGEM RIVER AND THE DURATION OF THEIR PROCESS OF FORMATION[1]

by

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Preserved in the northern slope of the central Caucasus, at Aktoprak settlement, on the upper Chegem, is a peculiar formation of silty argillaceous deposits which make up a 180 to 200 m-high river terrace. Because of its good exposure and its interesting and graphically expressed relationship with other genetic types of Quaternary deposits, as well as the presence in it of these peculiar concretions, the Aktoprak section has attracted the attention of many students ([6], etc.). D. S. Kizeval'ter and Ye. Ye. Malanovskiy relate its origin to a glacial lacustrine basin which originated at the maximum phase of the first (Main) Upper Pleistocene Caucasian glaciation and persisted during its retreat. Going upstream along the axis of the valley, these deposits change in facies to poorly sorted fluvio-glacial boulder-gravel accumulations which, in turn, are replaced somewhat higher upstream by typical till-like deposits (according to Ye. Ye. Milanovskiy). The lake was formed by the damming of the Chegen valley by landslides coming down the steep slopes of the Skalistyy Range, a few kilometers below the edge of the glacier.

Going down the valley, the base of the lacustrine deposits is represented by a rapidly thickening sequence of landslide and partly glacial till consisting of rough and unsorted chunks and rubble of Upper Jurassic limestone and arenaceous and argillaceous Lower and Middle Jurassic rocks. The thickness of this lacustrine section ranges from 120 m in the axial part of the valley to zero along the lacustrine basin periphery. The period of its accumulation, judging from the count of varves for best-exposed individual intervals, is 16 (±5) thousand years.

Right after the accumulation of this section, and following the break-through and emptying of the lake, the river cut it to the rock bed, thus bringing the sediments from a diagenetic to a weathering stage. That perhaps has determined to a considerable extent the interesting aspect of this section in the study of concretion formation. The possibility of determining approximately the time of deposition of this sequence, the presence of concretions almost throughout its entire thickness, and the different duration of diagenetic stages in different beds all renders the Aktoprak section a unique object of study of the time and extent of concretion formation.

We traced the lacustrine section in detail, over its entire length, from its change to the fluvio-glacial boulder-gravel facier, in the south, to the landslide massif in the north (Figure 1). A total of eight sections were studied. In three of the most complete and best exposed, the concretions and the percent content of their different sizes were counted along with a standard lithologic study. A brief description of the three sections is given below. Their correlation (see Figure 2) was done on the assumption that the lake had been filled with water practically immediately following the damming of the valley, up to the brim of the dam. Consequently, the lower units of all these three sections should have been deposited more or less simultaneously.

Structure of the lacustrine sections. The base of this section in the axial part of the inundated valley (Figure 2, section 1) is represented by fluvio-glacial boulder gravels, ranging in thickness from 5-6 to 10-15 m, which change abruptly to clays. This member appears to be very uniform in composition, at first glance, being represented by whitish, slightly yellowish, poorly consolidated thin-bedded clay (Figure 3), including varieties more or less enriched in fine silty material. A characteristic feature of it, as already mentioned, is the presence of peculiar carbonate concretions.

A study of the texture and granulometry of the sediments and the features of the concretions and their distribution throughout the section permits its division into several members regularly changing into one another.

The lower 35 m are represented by clay with structures of underwater mass movement, alternating layers is 1 to 2 m and 0.5 to 3 m, respectively. The mass-movement clays are

[1] Konkretsii aktoprakskoy tolshchi r. chegem i dlitel'nost' protsessa ikh obrazovaniya.

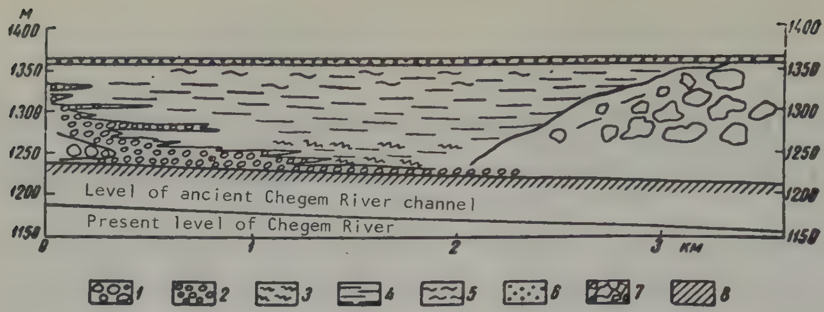

FIGURE 1. Diagrammatic cross-section of the lacustrine sequence.

1 - large boulder tilt deposits; 2 - boulder-gravel fluvio-glacial deposits; 3 - silty clay lacustrine deposits, with structures of submarine land creep in individual layers; 4 - silty clay lacustrine deposits, horizontally stratified; 5 - same, with wavy stratification; 6 - alluvial gravel deposits; 7 - landslide and other mass movement, partly glacial deposits; 8 - bedrock.

usually more homogeneous and thinner bedded, with large (diameter up to 20-25 cm) rounded isometric concretions; the horizontally stratified members include clay with some silty material and a considerable amount of large flattened, round to pancake-like concretions.

Higher in the section, there are alternating clays and silty clays (about 10 to 25 cm thick) with subordinate layers of fine silt. The layers of clay and silty clay, in their turn, display a finer horizontal stratification of a laminar type, finer (3 to 5 mm) and less distinct in clay layers, and coarser and more conspicuous (1 to 1.5 cm) in silty clay. Spherical, slightly oblate concretions are typical of the clay layers; the silty clays are characterized by greatly flattened to pancake-like ones.

The second member is marked by the presence of silty layers, 3 to 5 cm thick, in the lower 0.40 to 3 m. Their frequency increase in the middle part of the member, where there are occasional fairly large lenses and layers of silt, as much as 50 cm thick and several meters long. Both silt and silty clay often rest on clay with an uneven to pocket-like contact. There are fewer concretions here.

Higher in the section, there is a third member of more homogeneous clay, without silt and with a conspicuous lamination. Isolated clay layers display features of underwater mass movement but are considerably smaller than in the lower member. The number of concretions is about the same as in the upper part of the second member but considerably smaller compared to the first member and the lower part of the second. The presence of "manganese spots" is characteristic of these rocks. The third member is 25 m thick.

The lacustrine section is terminated by rapidly alternating silty clay and silt, one to 5-10 cm thick. The amount of silt increases upward. The silty layers are marked by shallow to gentle wavy partings and a gently wavy stratification, with one series of ripples truncating another ("current ripple marks"); the clay layers are characterized by a horizontal stratification. The lacustrine section is overlain conformably by alluvial gravel, the visible thickness of which is about 3 m.

Stratigraphic equivalents of these axial members of the lacustrine section are identifiable along the periphery of the lake where their thickness is considerably reduced. Specifically, in section 2 (Figure 2) of a peripheral portion of the lacustrine sequence at its contact with the bedrock slope, its thickness has been cut almost in two.

That section is characterized on the whole by finer sediments compared with the axial part of the lake. Its lower horizons are considerably thinner, partly because of the deposition and partly because of a creep of clay bodies down the underwater slope from the periphery to the middle of the lake. A layer of horizontally-bedded clay with chunks of bedrock is apparently equivalent to the lower member here. The second member, also much thinner, is represented by rapidly alternating clays of various degrees of siltiness with thin (2 to 3 cm) silt intercalations. Unlike the second axial member, the stratification here is always horizontal. The wavy silt-clay contact is absent, as a rule; instead, an excellent lamination has been developed. Both the first and the second members carry a considerable amount of round flattened concretions. The clays carry rough chunks and fragments of limestone and sandstone exposed above the lacustrine section, in ledges of Middle Jurassic shale on a high bedrock slope.

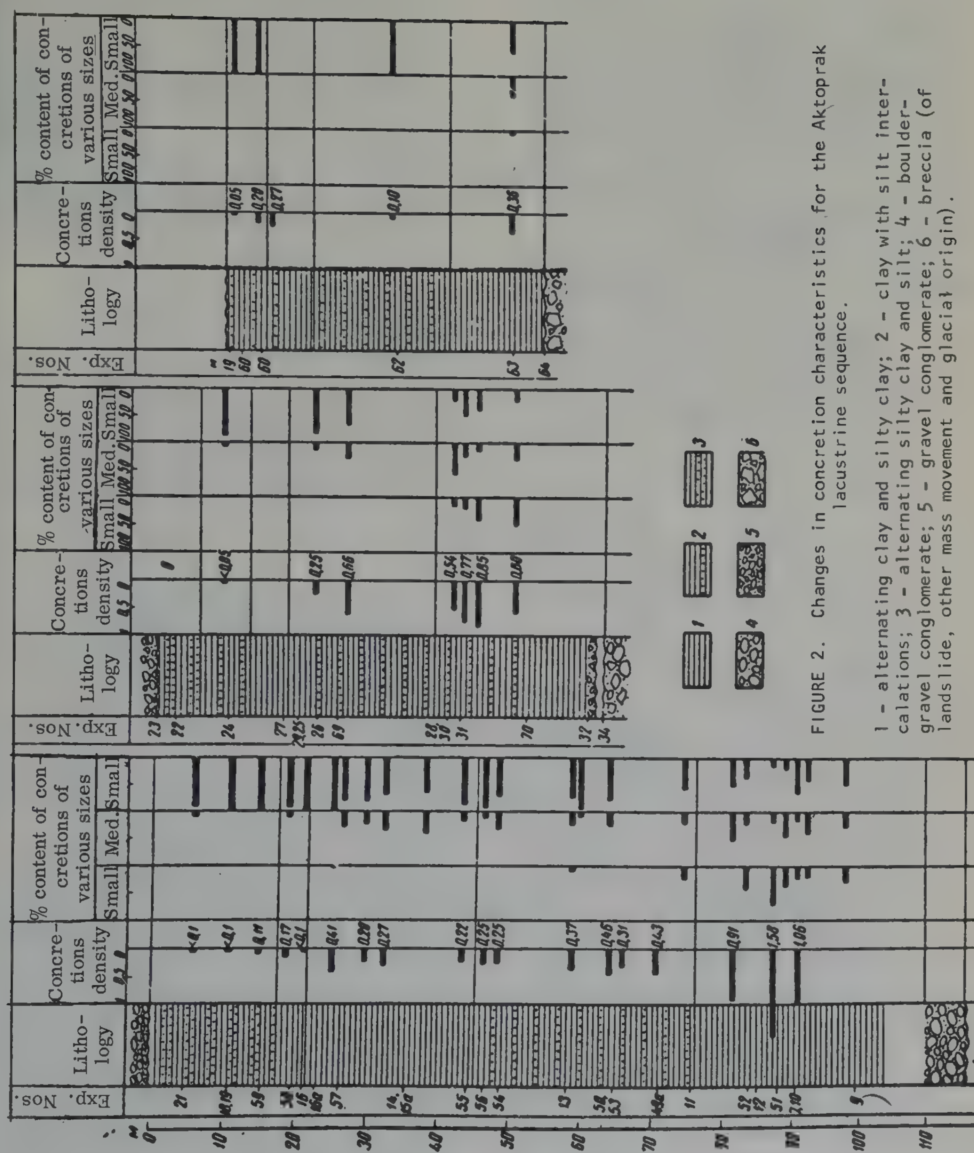

FIGURE 2. Changes in concretion characteristics for the Aktoprak lacustrine sequence.

1 - alternating clay and silty clay; 2 - clay with silt intercalations; 3 - alternating silty clay and silt; 4 - boulder-gravel conglomerate; 5 - gravel conglomerate; 6 - breccia (of landslide, other mass movement and glacial origin).

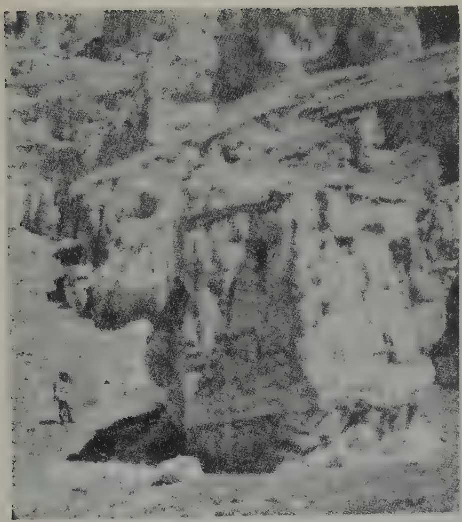

FIGURE 3. General view of exposures of the first (lower remnant) and second members of the Aktoprak section.

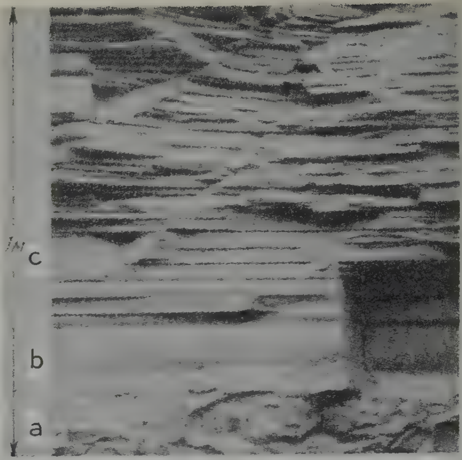

FIGURE 4. Clay from upper part of the sequence (exposure 16).

a - clay with small features of under-water mass movement, visible thickness 0.40 m; b - massive clay with "manganese spots", 0.20 m thick; c - horizontally stratified clay, visible thickness 1.20 m.

Higher up, the clay member with silty layers is replaced, as in section 1, by homogeneous clay with excellent laminar stratification and carrying occasional small concretions. This member contains a unit with underwater mass movement structures, correlative with a similar horizon in section 1.

Unlike section 1, the upper member here is marked by a predominance of clay over silt which alternates with it. The silt content is increased greatly only in the upper three meters, where wavy parting, similar to that in section 1, has been observed. This section, too, is terminated by culminates river gravel.

Section 3, also at the periphery of the lacustrine sequence but nearer to the dam, is similar on the whole to section 2. Its thickness here is also smaller (about a half), with the lower beds of the first clay member replaced in facies by cryptostratified, poorly sorted glacial-lacustrine clays cementing small chunks and rubble. The visible upper boundary of this section corresponds topographically to exposure 19 of section 1 (Figure 2). Here, as in section 2, the amount of silt is small, with thin silty layers distributed almost throughout the entire interval, except for its lower part which corresponds to he top of the first member in section 1.

An analysis of these sections reveals that the sedimentation conditions changed more than once during lacustrine deposition. The lower (first) clay member was deposited in the deepest basin (about 100 m deep), in immediate proximity to a glacier and was fed mostly by the finest glacial suspension (glacial milk). The accumulation of clay sediments on steep slopes of the lake bottom promoted a wide development of underwater mass movement, the evidence for which is present in the lower member of the lacustrine section. During the accumulation of silty clay of the middle (second) member, the basin was fed on the whole by coarser material whose importance in the section was growing periodically.

Slow currents were operative in the axial segment of the lacustrine basin and in its bottom parts, apparently caused either by seepage through the dam or by a temporary lowering of the lake level. After that, the deposition of finer clay sediments was resumed. During the last stage of its existence, the lake became very shallow, and cross-ripple marked silt began to be deposited along with clay. Soon (during the deposition of the upper gravel) the lake started to flow; finally after the dam had been broken through, the lake flowed out, and the lacustrine section was rapidly cut down to bedrock while its surface became a high terrace of Chegem River.

Concretionary formations. The presence of carbonate concretions, very diversified in form and dimensions (Figure 5), is typical of the entire lacustrine section, except for the upper 10 to 15 m. Their form is determined by the nature of the enclosing rocks, chiefly by their

FIGURE 5. morphologic varieties of concretions.

1, 2, 3, 4 - large isometric concretions from the first member, with irregularly, wavy deformed lamination visible in concretion 3; 5 - a strongly flattened "turtle" concretion from lower (1) member of the Aktoprak section (plan view); 6, 7, 9, 12, 13 - medium to small rounded flat concretion growths from bedded clay; 8, 11 - small rounded isometric concretions from upper part of lacustrine sequence; 10 - cross-cut of a manganese-calcium concretion, with dendrites of manganese oxide; 14, 15, 16 - small concretions and concretionary growths from upper part of the lacustrine sequence; 17 - manganese spots - "incipient concretions".

texture and to some extent by their granulometric composition. The following four principal morphologic varieties of concretions are present:

1) round flattened, lenticular to pancake-like, with the ratio of longest diameter to thickness greater than 3/1; they are peculiar to horizontally stratified clay;

2) isometric, round to irregular nodular concretions in massive unstratified clay and in layers with syngenetic mass-movement structures;

3) tabular layers originating usually in beds with a rapid alternation of clay and silt;

4) the so-called "incipient concretions" represented by small, vague dark-gray spots of manganese oxide.

The first and second varieties are the most common.

A common morphologic feature of the Aktoprak concretions is the prevalence of concretionary growths. Commonly, two or more lenticular concretions, of the same or different size and belonging to the same concretion layer, are joined along their long axes to form peculiar growths reminiscent of an opened pocket watch or eye glasses. There are also large round to oval, flattened concretions with smaller ones joined to them on all sides in turtle-like form. (Figure 5, [5].) Less common are tower-like or mushroom-shaped concretionary growths formed by the union of concretions from two adjacent horizons. The round isometric concretions, too, form growths but their junctions, unlike unctions of the flattened ones, are oriented in different planes. These growths, in turn, are enveloped occasionally in a common shell; some of these morphologic features of concretions are apparently peculiar to lacustrine basins of this periglacial type.

The relationship between concretions and the enclosing rocks do not appear to be any different from those in coal measures, for instance. In horizontally stratified members, the concretions are usually disposed in conformity with the bedding and strictly confined to definite concretionary horizons locally traceable for many meters. The distance between individual concretions in each bed varies greatly; in some places they follow one another almost without break, rosary-like; in others, the distance between them increases to 1 or 2 m. It is of interest that in most concretionary horizons, the concretions are marked by a morphology of their own, expressed either in the degree of flattening or aspect of growth, or in the distance between them. The size of concretions is maintained within a certain range, in each bed.

Stratification of the enclosing beds is maintained within the concretions; the laminae of fine homogeneous clay become somewhat thick while those with a higher silt content persist almost without change within a concretion. Like their internal structure, their surface is affected to a considerable extent by the stratification of the enclosing silty clay; the surface of homogeneous massive clay concretions is smooth, but it is irregular, wavy and knobby in concretions of mass-movement clays (Figure 5 — [3]). The characteristic finely costate surface of flattened found concretions of stratified silty clay (Figure 5 — [6, 7, 9]) has been determined by the presence in the concretionary body of laminae with a higher content of silt, chiefly of quartz.

The concretions vary greatly in dimensions; on the whole, however, as seen in Figure 3, they grow progressively smaller from the lower horizons to the upper. The largest concretions have been observed in the lower member of section where their diameter reaches 30 or 40 cm; the smallest ones (1 to 5 mm in diameter) occur in upper horizons of all three sections. Changes in the percent content of concretions throughout the section, as differentiated into three groups are as follows: large (diameter >10 cm), medium (t to 10 cm), and small (diameter <5 cm, mostly <2 cm). They are shown in Figure 2. The graphs in that figure show that concretions of all three groups are present in the lower lacustrine member, with groups one and two (large and medium) predominating, especially in section 1. Large concretions are rare in the second member and are altogether missing in the upper two. Conversely, the importance of small concretions is greater in the upper two members. The upper lacustrine horizons carry exclusively small specimens along with the "incipient concretions".

The density of concretions in various parts of the section is not the same. On the whole, it progressively decreases upward, until the concretions utterly disappear in the uppermost interval; in detail, however, it depends on the lithology of the rocks. Concretions are usually more numerous in fine clay rocks; their number is reduced sharply in silts, provided however that the latter form more or less thick layers. Where silts occur in a rapid alternation with clays, the concretion-making process is operative in the silts, as well, forming slightly mineralized concretionary layers. The thickest lentils of silt are free of concretions, although the number of concretions in adjacent clay layer may be very high.

The density of concretions for the three sections was determined by the linear method from a number of intervals; for silt-clay members the most argillaceous intervals were selected, whenever possible. The counting method used has been described in the literature [4]. The concretion density figures are not high, on the whole, less than 2%. These figures may be somewhat underestimated because the count was

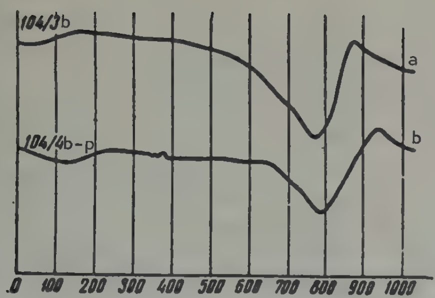

FIGURE 6. Thermal curves of manganese oxide.

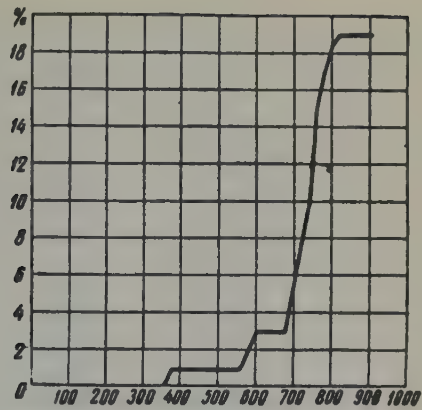

FIGURE 7. Loss of weight in heating, in %.

done on weathered faces, where some of the concretions possibly may have fallen out. (A trimming of exposures was difficult because of the toughness of the clay, in most places.) The concretion density changes are illustrated in Figure 2.

The upward decrease in the concretion density is best shown in section 1 which we studied in most detail. The maximum concretion density for this section has been observed in the first member where it is 0.9 to 1.58%. In the second member it decreases to 0.25 - 0.31%; in the third, to 0.20 - 0.27% (rising to 0.41% in one count). It drops to 0.1% at the base of the fourth member. In the upper 10 to 12 m, concretions are virtually absent, with only isolated finest (2 to 3 mm) nuclei occurring in places.

This lowering in the concretion content upward is true for the other sections; significantly, in section 2, as in section 1, the concretions practically disappear at a depth of 10 to 12 m and their number is very low down to a depth of 25 m.

It is quite obvious that this tendency for a lower concretion density upward has no doubt connection with the granulometric composition of rocks. Thus, in section 1, the concretion density decreases not only in the passage from the first clay to the second silty-clay member but in the passage from the second to the third clay member. In section 2, a decrease in the concretion density by a factor of almost three (from 0.60% - 0.85% to 0.25%) has been observed in the upper part of the homogeneous silty clay second member; in the third member, very uniform and represented chiefly by clays (with only 1 to 2% silt), the concretions account for 0.36% of the lower portion and drop to 0%, again as in section 1, at 10 to 12 m below the base of the upper gravel.

The concretions consist of about 50% carbonate substance (concretion maker), and of a terrigenous clastic fraction represented by finely dispersed clay: mica, hydromica, and quartz. The composition of this concretion maker is fairly uniform. As shown by chemical analyses[2] (Table 1), most of it is $CaCO_3$ (83 to 92%), with $MnCO_3$ present in very variable but considerably smaller quantities, from a fraction of 1% to 13.85%. In most specimens analyzed, the amount of $MgCO_3$ and $FeCO_3$ does not exceed 2 or 3%, with 6 to 8% $MgCO_3$ in some isolated analyses. A hydrochloric acid extract appears to contain, besides the carbonates, a small amount of leptochlorite.

The mineral composition of carbonates is determined by immersion, thermal analyses and by staining. The most common are calcite and manganocalcite, with the $CaCO_3/McCO_3$ ratio 1/8 to 1/10, and with the refractive indices (ω) ranging from 1.670 to 1.688. The presence of $CaCO_3$ has been corroborated by staining. A mixture of strong nitric acid and 20% potassium ferricyanide, in the presence of manganocalcite, produced a fairly intensive brown coloring.

The results of thermal analysis also have confirmed the presence of manganese carbonate.[3] As seen in Figures 6-a and 6-b, the endothermal (calcite) effect has been shifted to the left of 800°C; it is followed by a small exothermal effect and a downward trend of the curve, which is typical of $MnCO_3$. Especially distinct is the presence of $MnCO_3$ on the weight loss curve, which occurs, judging from the decomposition

[2] The chemical analyses were done in the Chemical Laboratory of Geological Institute, under the direction of E.S. Zalmanzon and partly in the Geology Department Laboratory, Moscow State University.

[3] The thermal analysis was done in the Coal Geology Laboratory, Acad. of Science USSR, by V.V. Koperina.

TABLE 1

Chemical analyses of concretions

Nos.	Specim Nos.	Specimens	Insoluble mineral residual	Al_2O_3	Fe_2O_3	FeO	MnO	CaO	MgO	CO_2	Sum	C_{org}	P_2O_5	$Ca_3(PO_4)_2$	MgO silica	FeO silica	% of carbonates, with arithmetic average for $MgCO_3$ and $FeCO_3$: $CaCO_3$	$MnCO_3$	$MgCO_3$	$FeCO_3$
		Large	Concretions from the lower part of section (zoned structure)																	
1	11-a-p	Peripheral shell	43.22	5.06	1.17	1.51	0.08	21.70	2.43	19.57	94.74	0.07	0.16	0.35	0.45	0.75	87.46	0.30	9.48	2.78
2	11-a-m	Middle	42.32	4.12	2.33	1,58	2.36	21.70	2.59	19.05	96.05	0.11	0.18	0.39	2.26	1.02	87.64	8.73	1.58	2.06
3	11-a-c	Central core	43.18	4.67	1.38	1.65	3.33	21.50	2.74	18.98	97.43	0.07	0.07	0.15	2.69	1.58	87.18	12.29	0.23	0.30
		Medium																		
4	104/4-b-p	Peripheral shell	46.64	3.32	2.28	1.07	2.76	20.74	1.62	17.90	96.65	0.08	0.24	0.51	1.31	—	85.87	10.74	1.32	2.07
5	104/4-b-c	Central core	46.00	2.80	1.49	1.26	2.70	21.72	1.53	18.70	96.62	0.07	0.27	0.58	1.53	1.06	88.46	10.13	0.78	0.63
6	10-b	Central shell	50.08	2.04	1.53	1.15	2.26	20.29	1.86	17.90	97.11	0.14	0.16	0.35	1.52	0.58	87.17	8.89	1.71	2.23
7	7-a-p	Peripheral shell	43.04	5.74	4.78	0.28	1.54	20.20	2.90	16.85	95.33	0.03	0.16	0.35	2.81	0.14	92.49	6.48	0.48	0.57
8	7-a-c	Central core	41.64	6.11	1.34	2.04	2.23	21.25	1.70	19.34	95,65	0.08	0.16	0.35	0.98	1.02	84.74	8.14	3.43	3.69
9	104/3-a	Peripheral shell	49.87	0.05	6.86	1.52	0.06	19.99	2.17	16.30	96.82	—	Not det'd.		2.17	1.59	96.26	0.27	1.45	2.02
		Small	Concretions from upper part of section (homogeneous structure)																	
10	59	—	43.42	3.32	1.43	1.80	3.76	22.55	0.77	20.75	97.80	0.07	0.01	0.02	0.77	0.62	83.88	12.70	1.44	1.98
11	61-b-1	—	42.92	3.40	1.26	1.44	3.22	23.45	0.77	21.10	97.56	0.10	Not det.		0.77	0.31	86.04	10.73	1.36	1.87
12	16-a	—	47.36	1.90	0.65	1.29	3.73	22.17	2.27	20,03	99.40	0.05	0.20	0.44	2.04	0.88	89.73	13.85	1.10	1.51
			Thin concretionary layers from upper part of section																	
13	61-b-3	—	46.50	4.35	1.41	1.29	0.14	22.11	2.10	18.68	96.58	0.08	0.18	0.39	1.19	0.64	92.47	0.53	4.54	2.46

Refractive indices (ω) for carbonate minerals

1. 1.658! un. 1.670 (up to 1.683)
2. 1.664! 1.658, un. 1.670, 1.678, 1.682
3. 1.670! 1.658, un. 1,682
5. 1.670! 1.658; un. 1.690
6. 1.664! 1.670, 1.658; un. 1.682
7. 1.658! un. 1,670
8, 1.658! 1.670! 1.682
10. 1.681—1.688! 1.670, 1.658
11. 1.670! 1.658, un. 1.682
12. 1.670—1.678! 1.658: un. 1.682
13. 1.658! un. 1.670

of the carbonate, in the 550 to 650°C interval (Figure 7). The presence of some dolomite (ω = 1.682) may be assumed in isolated samples characterized by a somewhat higher $MgCO_3$ content (3.4 to 9.48%). Iron carbonate is present in insignificant quantities as an isomorphic addition to manganocalcite and possibly to calcite and dolomite. Magnesium siderite has not been observed.

As seen under the microscope, the carbonates are represented by a cryptocrystalline to finely crystalline dark brown mass. The crystal size is determined in the final count by the crystallization conditions for a carbonate rather than by its composition. In the presence of silty material, both calcite and manganocalcite usually acquire a finely crystalline structure (crystals up to 0.01 mm); in concretions originating in homogeneous clay, the carbonate substance usually is cryptocrystalline (0.001 mm). In concretions with a thin-bedded structure, due to the presence of silt material, there often is a 10 to 12 fold decrease in size of carbonate grains in two adjacent laminae. Strongly weathered specimens (only fresh specimens were used in the chemical analysis) show under the microscope rounded, branching to dendritic, fairly well-outlined inclusions, transparent at the edges, with a reddish hue. These are dendrites of manganese oxide (Figure 5 — 7). Depending on the degree of weathering of a concretion, these inclusions are present either only at its periphery or they take in its core, also, where they occur in numerous dot-like incrustations. The remaining terrigenous material of the concretions is represented by a poorly crystallized clay mass, strongly corroded quartz, and scales of mica and hydromica. Feldspars are less common.

Compositional zonation in the concretion. All large concretions display a change in carbonate composition from the center to the periphery. Specifically, a certain enrichment of the core in manganese carbonate has been observed (8 to 20% total carbonate compared with 0.2 to 6% at the periphery) along with a growth in importance of $CaCO_3$. The zonal distribution of carbonates is excellently demonstrated by staining and is graphically corroborated by chemical analyses and a determination of refractive indices. The core of large concretions is taken over mostly by manganocalcite (ω = 1.664 to 1.670), while their periphery is mostly calcite. Maximum amounts of $MgCO_3$ have been observed in the peripheral shell of concretions but no regularity in the distribution of magnesium carbonate has been established. According to analytical data and to the result of straining of numerous concretion sections for iron carbonate, the iron carbonate content in their peripheral parts appears to be somewhat higher.

It is of interest that the concretion-maker of small concretions in the upper lacustrine beds is similar in composition to the central part of large concretions, both characterized by a high $MnCO_3$ content. This is well demonstrated in the table of chemical analyses (Table 1).

The comparative enrichment in manganese throughout the entire body of small concretions was obvious in a macroscopic study, as well; on weathering, they usually are covered by a brownish-red film while coarse concretions in the middle and lower horizons remain yellowish white. This regular change in the composition of carbonate minerals within concretions suggests two stages of formation: in the first stage, both manganese and calcite were redistributed in the sediments; in the second stage, the importance of manganese was reduced markedly while that of magnesium and iron possibly became somewhat greater. Small concretions in the upper lacustrine beds were terminated at the initial stage while large concretions in the lower beds went through both formational stages.

Composition of the enclosing rocks. As already noted, the Aktoprak section is made up mostly of hydromicaceous clay (with some addition of silty material) and of silt. Main components of the silt, and to a smaller extent of clay rocks, are clastic grains of quartz, feldspars, and mica. It is significant that the feldspars are very fresh.

The clays soak up water and become plastic. According to mechanical analysis data cited by V. P. Rengarten (1935), predominant in them is the 0.01 to 0.005 mm fraction (0.001 mm); the colloidal fraction is only 8.55% (Table 2). As shown by an electron-microscope study, the latter fraction is wholly represented by hydromica.

The distribution of CO_2, C_{org}, Fe_{total}, Mn_{total}, and P for a number of samples of clay and silt from various horizons is given in Table 3.

As seen in this table, the CO_2 content in clay ranges narrowly, from 0.02 to 0.24, i.e., the clays are either very slightly carbonate or virtually carbonate free. The carbonate content in clay apparently is reduced for the second time through leaching in weathering. The clays are very poor in organic carbon, present in hundredths of a percent. The total iron, manganese, and phosphorus content appears to be normal (Clark coefficient), in most samples. Iron occurs in higher concentrations, in some layers, because of films of iron hydroxide in bedding planes. The analyses of such clays are given in Table 4.

The two chemical analyses of silt at hand show that their carbonate content is variable (0.144%), the content of manganese and total iron is cut more than in two compared with clay, while that of phosphorus is somewhat higher.

TABLE 2

Fraction in mm	0.25–-0.05	0.05—-0.01	0.01–-0.015	0.015–-0.001	0.002
% content	0.12	7.18	75.15	9	8.55

An attempt was made to determine the state of iron in two samples. One of them was an almost white slightly silty clay; the other, a yellowish clay in fine suspension. As seen from figures in Table 5, pyritic iron is practically absent in the clay; this has been fully corroborated by microscopic data. In one sample, the total iron was represented by ferric iron in clastic minerals; in the second sample, all forms of iron were present, except for the pyritic. However, inasmuch as these samples were taken from weathered zones, their analyses should be regarded with reservation.

concentration of iron in the lacustrine section concretions; the Clark coefficient for the phosphorus concentration is 2; and the manganese concentration is 25 times higher, on the average. In central parts of concretions, the Clark coefficient for manganese reaches 35; in peripheral parts, it ranges from 1 to 15. The CaO and MgO content has not been determined in our samples. According to the analytic data of E. E. Carstens and Reinford, given below, the amount of CaO in clays ranges from 1. 95 to 2. 20; of MgO, from 1. 27 to 2. 30. Correspondingly, the Clark coefficient of their concentration is 8 to 10 and 1 (Table 7).

Thus, manganese turned out to be most active in the process of diagenetic redistribution of matter in sediments of the lacustrine section, followed by less active calcium and phosphorus. Iron and magnesium practically did not participate in the building of concretions. The main factor determining the passive role of iron, despite its considerable content in the enclosing rocks, even somewhat larger on the average than in iron-rich argillaceous rocks of coal

TABLE 3

Chemical analyses of clays

Samples Nos.	Rock	C_{org}	Fe_{total}	Mn_{total}	P	CO_2
	Lower part of the section					
7-b	Clay	0.06	5.23	0.09	0.005	0.02
11-b-1	"	0.03	5.23	0.08	0.024	0.04
104/4-c	"	0.09	5.57	Not det.	Not det.	0.24
13-a	"	0.14	7.58	—	»	0.16
104/4-a	Silty clay	0.11	4.51	Not det.	»	0.06
10-b	Silt	0.08	2.04	0.04	0.071	4.20
11-b-2	"	0.05	2.19	0.03	0.071	0.10
	Upper part of the section					
15-a[1]	Clay	0.05	6.38	—	Not det.	0.06
16	"	0.03	4.33	1.04	0.048	0.18
24	"	0.13	3.84	1.07	0.005	0.16

The state of the iron was also determined for some concretion specimens (Table 6). The ratio of various forms of iron in concretions is similar to that in the enclosing rocks.

It appears from a comparison of total iron, manganese, and phosphorus in concretions and the enclosing rocks (taking into account that terrigenous material in concretions was diluted by carbonates amounting to almost half of its volume) that there has been hardly any

measures, is their insifinificant C_{org} content. This low content of organic carbon has caused the nearly total lack of iron carbonate even in

TABLE 4

Sample Nos.	Fe_{total}	Mn_{total}	C	CO_2
61-a	8.0	0.40	0.13	0.42
16-g	8.54	None	0.96	0.51

TABLE 5

Sample Nos.	Fe_{total}	$Fe^{-2}_{over-all}$	$Fe^{-2}_{solut.}$	S	$Fe^{-2}_{pyr.}$	$Fe^{+3}_{solut.}$	$Fe^{+3}_{over-all}$	C_{org}
104/4-a	4.51	None	None	0.01	0.01	None	4.5	0.11
104/4-c	5.57	2.83	2.48	None	None	0.35	2.74	0.09

peripheral parts of the Aktoprak concretions, unlike the calcium carbonate concretions from the coal measures, always enriched in iron carbonate to some extent, in surface shells [5].

Correlatives of the Aktoprak concretions. It is interesting to note that carbonate concretions similar to hose of the Aktoprak section are known from a number of Quaternary clays of similar origin, formed in periglacial lakes. In North Caucasus, they have been observed in Upper Pleistocene lacustrine deposits of the Gizel'don valley. A number of authors have long since described the so-called "Imatra stones" from the Vuoksa River valley, near Imatra falls in southern Finland. They are peculiar limestone concretions in gray laminated late-glacial lacustrine clays. Judging from their description by P. N. Venyukov [1], the "Imatra stones" are very similar to the Aktoprak concretions, in morphology, relationship with the enclosing rocks, chemical composition, and specifically in manganese enrichment. In dealing with the origin of those "Imatra stones", somewhat enigmatic to earlier students, P. N. Venyukov has come to the correct conclusion about their concretionary nature. He states, "They were formed in clay and they borrowed their material mostly from it and cemented it by lime carbonate from the same clay".

According to P. N. Venyukov, concretions similar to the "Imatra stones" occur in late-glacial lacustrine clays of the Ladoga basin, and also in Sweden, Norway, and other Baltic regions. N. A. Yefimtsev [2] has noted recently the presence of carbonate concretions in clay deposits of periglacial Pleistocene lakes of the Altay. Judging from his photographs, the Altay concretions are startingly similar to the Aktoprak.

TABLE 6

Sample Nos.	Fe_{total}	$Fe^{-2}_{over-all}$	$Fe^{-2}_{solut.}$	S	$Fe^{-2}_{pyr.}$	$Fe^{+3}_{solut.}$	$Fe^{+3}_{over-all}$	C_{org}
104/3-c-p	3.18	1.64	1.31	0.05	0.04	0.33	1.83	0.07
104/4-c	2.88	1.34	1.02	0.03	0.03	0.32	1.54	Not det.
104/4-c-p	2.75	1.17	0.98	0.01	0.01	0.18	1.56	0.05
104/4-c-p	3.04	1.10	0.83	0.03	0.03	0.27	0.94	0.08

These data suggest that manganese-calcite concretions of the Aktaprak type are typical of clay and silty clay laminated deposits of periglacial Quaternary lakes; as such, they appear to be a typical genetic feature of these sediments.

The origin and time of formation of the concretions. Concretions of the Aktoprak section undoubtedly are of a diagenetic nature.

1. The formation of concretions began not in the surface layer but at depths of about 10 m. This is suggested by their disappearance in the 10 to 12 m interval below the top. The formation of concretions at some depth is also suggested by the fact that in beds with structures of submarine mass movement, 2 to 3 m thick, even the central parts of large concretions, judging from their isometric form, began to be

TABLE 7

Sample Nos.	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Ignition losses
—	48,29	30.05	7.01	2.10	1.27	—	10.94
381	61,80	20.75	7.50	2.05	2.32	0.45	4.36
384	61.48	20.55	7.95	1.95	2.30	0.55	4.56
387	62.88	21.45	7.30	2.20	2.10	0.37	3.20

formed after the disturbance. An analysis of their quantitative distribution throughout the section reveals that a more or less intensive formation of concretions began at a depth of about 20 m.

2. The concretion formation process, judging from a progressive increase in the size and number of concretions, going down the lacustrine section, went on throughout the entire period of accumulation, i. e., for 16,000 ± 5,000 years. During that time, concretions in the lower part of the section passed through two formation stages (manganocalcite and calcite) while the upper concretions were terminated at an early manganocalcite stage. Thus, the thickness of the sedimentary section involved in the process of concretion-making here is on the order of 100 m. These data are in full accordance with N. M. Strakhov's [3] views on the duration of diagenetic redistribution of matter and on the average thickness of a diagenetic zone which he estimates to be several tens of meters.

3. Concretion formation ceased soon after the deposition of the upper lacustrine beds, because of a sharp drop in the lake level followed by erosion of the section, down to its base.

This genetic relationship between rocks and their concretions, and the distribution of concretions throughout the section, rule out the possibility of concretion-making in a catagenic zone.

Recently determinations of the absolute age of the concretion formation by the C^{14} method appeared in the literature. Thus, H. Pantin [7] has estimated that some 7,500 years were needed to form Upper Quaternary marine calcareous concretions from the southeastern shelf of the New Zealand coast (Cape Campbell). The order of magnitude of this figure is very close to that obtained for the Aktoprak concretions.

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THE PROBLEM OF INDEPENDENCE OF THE TAZ GLACIATION IN WESTERN SIBERIA[1, 2]

by

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That the Taz glacial deposits represent a stage of the retreat from maximum glaciation in the Taz basin, western Siberia, was first suggested by N. A. Naginskiy [10] from A. A. Zamtsov's data. The wide distribution of these deposits was subsequently determined by S. B. Shatskiy [11], A. A. Zemtsov [3, 4], S. A. Arkhipov and Yu. A. Lavrushin [1, 2, 7], V. A. Zubkov [5, 6], and others. However, up to the present time, the independence of the Taz glaciation has been open to lively discussion. A number of students including S. B. Shatskiy [4, 11], V. A. Zubkov [6], and A. A. Zemtsev, believe in its independence, while some others, S. A. Arkhipov, Yu. A. Lavrushin, Ye. V. Koreneva [1, 7], and B. V. Mizerov [9], regard it only as a stage of the maximum west Siberian Samarian glaciation.

The advocates of an independent Taz glaciation use for their argument the scant palinologic data from intermorainal alluvial deposits, inadequate for a definite solution of this problem. Thus, S. B. Shatskiy and A. A. Zamtsov base the supposed interglacial nature of the intermorainal sequence on the presence in it of peat-carrying beds and even lenses of peat [3, 4]. In a peat-carrying layer from intermorainal sands along the middle course of Karal'ka River, V. P. Nikitin identified sprouts, seeds, and spores of the following plants: fungi, Selaginella selaginnoides L., (link), Pinacea gen. Juncus cf. Zampocarpus Ehrh., Betula sp., Ranunculus hyperboreus Rottb., Comarum palustre L., Viola palustris L., Lysimachia tryrsiflora L., Menyanthes trifoliata L., and Lycopus europeans L.

A layer of sandy peat has been observed in an intermorainal sequence of the Vatyl'ka River basin. It carries remains of the following plants: fungi, Sphagnum, Mnium, Carex sp., Juncus cf. arcticus Willd., Ranunculus sf. hyperboreus Rottb., Comarum palustre L., Potentilla sp., Lysimachia tryrsilflora L., and Lonicera altaica Pall. [4].

I. M. Pokrovskaya identified in the laboratory of the All-Union Geological Institute the spores of Sphagnum, Lycopodium, and Polypodiaceae. The pollen of tree plants belongs to the genera Pinus, Picea, and Alnus, with the Picea and Betula pollen predominant. This assemblage is marked by the great variety of grass pollen: Carex, Carephyllaceae, Graminiae, Polygonaceae, Crenopodiaceae, Amaranthoceae, Leguminosae, and Ericaceae [4]. S. B. Shatskiy and A. A. Zemtsov note that neither assemblage contains plants either more warmth-loving or more cold-loving than those presently growing in that region. This led them to the conclusion that climate contemporaneous with the formation of these deposits had not been different from the present one. For that reason, the two authors assign deposits containing the abovenamed plant remains to an interglacial stage.

However, an analysis of these floras reveals that they are represented on the whole by intrazonal species which do not necessarily suggest an interglacial nature of the intermorainal sequence. Spore and pollen analysis is not much help because of the lack of a quantitative description of the content of each species and the lack of the ratio of woody plants to grasses. In our opinion, all this prevents a definite conclusion as to the interglacial nature of this flora, at the present time.

The second view, according to which these intermorainal deposits are one stage among others, is also based chiefly on paleobotanic data; it was shared until recently by one of the authors of this paper (Yu. A. Lavrushin). Our 1958 field work has yielded new data which point to the interglacial nature of the intermorainal sequence. As a result, we how share the view favoring the independent nature of the Taz glaciation.

The intermorainal sequence is represented on the whole by alluvial and alluvial-lacustrine

[1]K voprosu o samostoyatel'nosti Tazovskogo oledeneniya Zapadnoy Sibiri.

[2]This paper has been written from geologic data of Yu. A. Lavrushin, spore-pollen analysis by A. I. Permyakov, and the results of a carpologic analysis by Yu. M. Trofimov. The basic conclusions are those of all three authors.

deposits and has a definite local distribution in major erosional-tectonic troughs of the Yenisey and Turukhan type, and in valleys of the Taz and Pur basin. In northern regions, this alluvial formation is replaced in facies by littoral marine sediments carrying arctic-boreal, arctic, and sub-arctic species of a Quaternary marine fauna [4].

Within the Yenisey basin, intermorainal deposits are known as the Messovsk-Samburgsk unit [1, 2] or Khakhalevsk beds [5, 6]. Correlative with them in the Taz and Pur basin is the Shirtinsk alluvial unit [4].

Often present within the Yenisey trough, in the right bank exposures below marine-glacial deposits of the Taz-Sanchugov (Yenisey) unit, is the Messovsk-Shirtinsk alluvium underlain by the Samarian moraine deposits [1, 3, 4, 7].[3] Judging from drilling data and from natural exposures, the thickness of that formation ranges widely, from 8-10 to 30-40 m. However, only its uppermost part is exposed in most outcrops. Quite distinct in the alluvial sequence are channel, flood, and oxbow facies, as well as delta deposits.

The nature of changes in the alluvium, from north to south, can be clearly traced in exposures along the right bank of the Yenisey, beginning at Pupkovo station. Exposed here below a marine-glacial section is the Messovsk alluvium represented by steeply dipping layers of sand and loam. They have a conspicuous thin stratification, parallel to the base and top of the beds, usually dipping to the north. The length of layers, and consequently of laminae, is 3 to 4 m. The layers are 1.0 to 1.3 m thick. These deposits undoubtedly belong to a deltaic type of bedding and appear to represent a submarine portion of the Yenisey delta pushed out into a shallow estuarine embayment, possibly similar to the present Yenisey mouth. The loam layers evidently suggest periodic stages of silting up of the delta. The regular alternation of sandy and clayey layers, too, suggests periodic changes in the sedimentation conditions.

The formation time of these deposits is naturally correlative with the beginning of a boreal transgression in northern regions which brought about the formation of a freshwater estuarine embayment in the Yenisey valley and an accumulation of deltaic deposits. Farther upstream, however, alluvium was formed at the same time, similar to the standard river alluvium of coastal plains, as described by Ye. V. Shantser, in structure and facies features.

Most interesting for the purposes of this work are alluvium exposures of the intermorainal section on the right bank of the Yenisey, 2.5 km above Zyryanovo station and 0.5 km above the Komsa mouth.

Exposed below the marine-glacial deposits in the first exposure, 0.75 m above the water edge, is oxbow alluvium of dark gray, somewhat smoky blue, medium-fine, thin flat-bedded, strongly micaceous loam. Their stratification is emphasized by fine intercalations of dark-brown peat. At 0.1 m above the edge of the water, the section becomes somewhat sandier, then turns back to loam. Numerous pseudomorphs of ice wedges 0.4 to 0.5 m in size are quite conspicuous in the section. They are traceable for 2 to 3 m along the inclined underwater surface of a channel shoal.

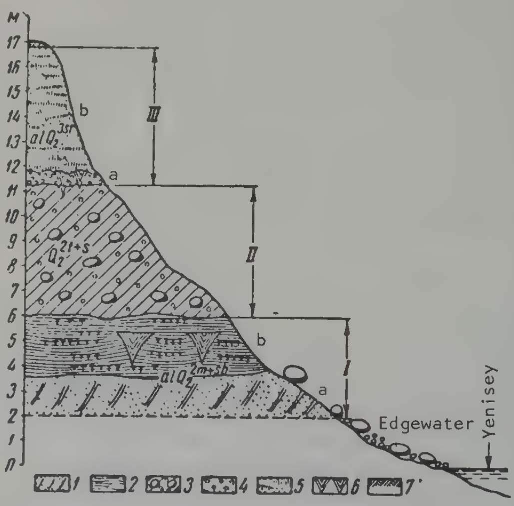

FIGURE 1. Exposure of the Messovsk-Shirtinsk deposits in the right bank of the Yenisey, 0.5 to 1.0 km above the Komsa mouth.

1 - Cross-bedded sand; 2 - loam with plant remeans; 3 - loam with boulders and gravel; 4 - sand with pebbles; 5 - sand with intercalations of loam and sandy loam; 6 - frost deformation; 7 - present soil.

I - alluvium of the Messovsk-Shirtinsk horizon: a) deposits of estuarine shoals; b) floodplain alluvium; II - the Taz-Sanchugov marine-glacial deposits; III - alluvium of the Number I terrace: a) channel alluvium; b) floodplain alluvium.

Samples for spore-pollen analysis were collected from an interval undisturbed by frost deformation. The results are presented in Figure 2 which shows that the vegetation cover of that period was characterized by taiga (virgin forest) features. This is suggested by an

[3]Many students (B. V. Mizerov, S. B. Shatskiy, V. A. Zubakov, S. A. Arkhipov, Yu. A. Lavrushin) correlate the Tazov glaciation deposits with the Sanchugov unit representing a boreal transgression of West Siberia, first identified by V. N. Saks. This explains the doublt name of this unit and the complicated origin of its deposits.

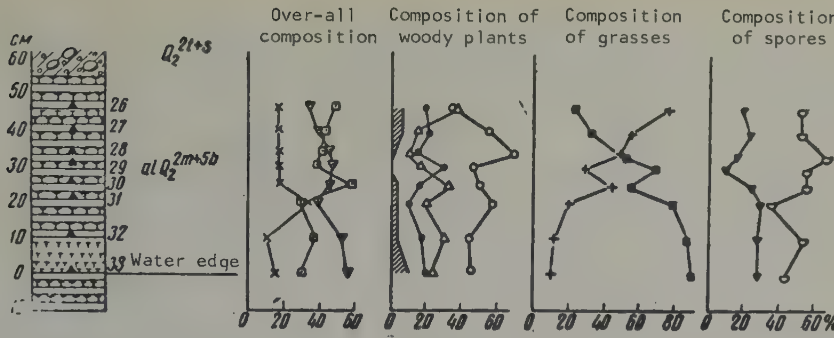

FIGURE 2. Spore-pollen diagram for Messovsk-Shirtinsk deposits from exposure on the right bank of the Yenisey, 2.5 km above Zyryanovo.

1 - woody pollen; 2 - grass pollen; 3 - spores; 4 - Abies; 5 - Picea; 6 - Pinus; 7 - Betula; 8 - Artemisia; 9 - mixed grasses; 10 - Polyglaceae; 11 - Sphagnum; 12 - Alnus.

solute preponderance of tree pollen (30 to 50% d grasses 10 to 15%). The remaining compon- ts are spores of ferns and mosses.

Birch pollen is most common among the woody ant group (40 to 60%); it decreases markedly ing up the section, approaching the marine- acial deposits. Pine pollen constitutes 20 to % on the average; fir pollen, 5 to 10%.

Diversified grass pollen predominates near e base of the section (up to 90%, with 10% of rtemisia pollen). Going up the section, Arte- isia increases in abundance reaching a maxi- um of 80% at the very top. This upward in- ease in Artemisia and birch pollen content ggests the onset of a cooler climate. A marked crease in the fir pollen content in the upper rt of the section appears to point in the same rection.

These analytic data suggest that during time accumulation of the deposits in question in is area, a flora fairly similar the present ne, namely pine-birch, cedar-birch,[4] and oruce-birch forests with a very considerable, rhaps locally predominant, growth of fir, hagnum mosses, and ferns existed.

The presence of ice wedge pseudomorphs in luvial deposits suggests the prevalence of ermafrost, at that time. However, this does ot mean at all that the contemporaneous cli- iate was colder than that of the Holocene. An nalysis of data on the present distribution of ermafrost points to its very wide development nd considerable thickness.

Our study of the Uenisey alluvium has shown iat evidence of the permafrost effect on the ood plain structure is especially clear in the lder floodplain terraces and is missing in younger segments. Furthermore, the effect of permafrost on the alluvial structure is manifest usually under sufficiently favorable conditions, which depend first of all on the degree of moisture in the rock at the time of autumn frost, on the lithology of sediments, etc. Considering all these data, set forth in detail in another paper by the present authors, it may be assumed that climatic conditions during the formation of upper Messovsk-Shirtinsk alluvium apparently were similar to climatic conditions of early Holocene and corresponded to the end of the interglacial age. A similar conclusion is reached from a study of the second exposures. The Komsa mouth section has a similar constition. Underlying the marine-glacial deposits is the Messovsk-Shirtinsk alluvium. The section exposed here is as follows, reading upward:

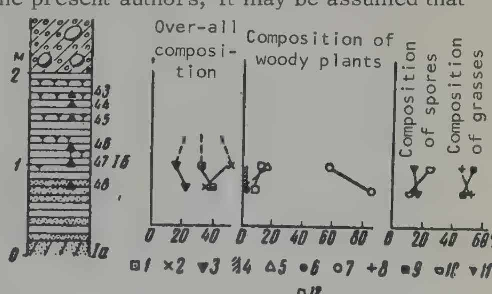

FIGURE 3. Spore-pollen diagram for the Messovsk-Shirtinsk deposits from exposure on the right bank of the Yenisey, 0.5 to 1.0 km above the mouth of Komsa River.

1 - woody pollen; 2 - grass pollen; 3 - spores; 4 - Abies; 5 - Picea; 6 - Pinus; 7 - Betula; 8 - Artemisia; 9 - mixed grasses; 10 - Polyglaceae; 11 - Sphagnum; 12 - Alnus.

1. A channel shoal facies of large lentils of interbedded fine-grained yellow polymictic sand.

[4]Siberian cedar (Pinus siberica) is meant. Its llen and that of Pinus silvestris occur throughout e section in about the same amount; their total is dicated in the diagram.

Summary of the Composition of Pollen and Spores from the Messovsk-Shirtinsk Interglacial Deposits

Names of spores and pollen	Exposure 2.5 km above Zyryanovo (sample numbers)																Exposures 0.5 km above the mouth of Komas (sample nos).											
	26		27		28		29		30		31		32		33		43		44		45		46		47		48	
	amount	%	amount	%	amount	%	amount	%	amount	%	amount	%	amount	%	amount	%	amount	%	amount	%	amount	%	amount	%	amount	%	amount	%
a) Over-all composition:																												
Woody plants	108	47	65	42	61	40	91	39	121	39	76	27	64	38	57	30	23	—	1	—	2	—	6	—	85	32	81	40
Grasses and semi-brush	41	18	28	18	28	18	40	17	52	17	97	34	18	10	29	15	20	—	2	—	3	—	9	—	137	52	77	38
Spores	82	32	63	40	64	42	101	44	137	44	110	39	90	52	106	55	27	—	1	—	3	—	4	—	43	16	44	22
Total pollen and spores	231		156		153		232		310		283		172		192		70		4		8		19		265		202	
b) Composition of woody plants:																												
Abies	6	6	3	5	1	2	—	—	3	2	3	4	1	2	6	11	—	—	—	—	—	—	—	—	2	2	2	2
Picea	41	38	9	14	7	11	15	16	39	32	14	18	19	30	13	23	6	—	—	—	—	—	2	—	15	16	—	—
Pinus sibirica	8	7	11	16	4	7	24	26	15	12	6	8	8	12	8	14	7	—	—	—	1	—	—	—	—	—	1	1
Pinus silvestris	10	9	1	1	3	5	3	3	4	3	2	3	4	6	3	5	1	—	—	—	—	—	—	—	—	—	—	—
Larix (?)	2	2	—	—	—	—	—	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Betula	41	38	36	56	43	70	40	44	58	48	43	57	29	46	25	44	9	—	1	—	1	—	3	—	55	65	73	90
Alnus	—	—	4	6	3	5	9	10	2	2	5	7	1	1	2	3	—	—	—	—	—	—	1	—	11	13	5	6
Salix	—	—	1	1	—	—	—	—	—	—	2	3	2	3	—	—	—	—	—	—	—	—	—	—	3	4	—	—
c) Comp. of grasses and semi-brush																												
Gramineae	—	—	—	—	2	7	19	47	7	13	25	26	—	—	2	7	—	—	—	—	—	—	—	—	14	10	2	3
Cyperaceae	—	—	2	7	1	4	2	5	6	11	47	49	15	83	16	55	8	—	—	—	—	—	—	—	19	14	13	17
Liliaceae	—	—	—	—	—	—	—	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Ranunculaceae	—	—	1	4	2	7	1	3	6	11	—	—	1	6	—	—	—	—	—	—	1	—	—	—	3	2	—	—
Thalictrum	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—
Rosaceae	—	—	—	—	1	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Rubus chamaemorus	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	4	—	—	—	—	—	—	—	—	—	—	—	—
Polygonaceae	—	—	1	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4	5
Caryophyllaceae	—	—	—	—	—	—	—	—	2	4	2	2	—	—	—	—	—	—	1	—	—	—	—	—	4	3	6	8
Leguminosae	—	—	—	—	—	—	2	5	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—
Chenopodiceae	—	—	3	10	4	14	4	10	—	—	—	—	—	—	2	7	6	—	—	—	—	—	—	—	15	11	10	13

Ericaceae	6	15	2	7	1	4	—	—	—	—	3	3	—	—	5	17	1	—	—	—	—	—	—	—	4	3	—	—
Plantaginaceae	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1
Umbelliferae	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	3
Compositae	3	7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5	4		
Artemisia	32	78	15	54	14	50	12	30	23	44	18	19	2	11	3	10	4	—	1	—	2	—	9	—	63	46	39	51
Sparganiaceae (?)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3	2	—	—
Myriophyllum	—	—	—	—	—	—	—	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Indeterminable grasses	—	—	4	14	3	10	—	—	8	15	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6	4	—	—
d) Comp. of spores																												
Polypodiaceae	43	53	36	57	47	74	54	54	82	60	40	36	47	52	48	45	14	—	—	—	1	—	2	—	10	24	5	11
Lycopodium	2	2	2	3	1	1	—	—	—	—	6	5	5	5	5	5	—	—	1	—	—	—	—	—	—	—	—	—
Selaginella	2	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Sphagnum	16	20	15	24	9	14	10	10	33	24	33	30	24	27	29	27	1	—	—	—	2	—	1	—	6	14	6	14
Bryales	18	22	10	16	7	11	37	37	22	16	31	28	14	16	24	23	12	—	—	—	—	—	1	—	27	63	33	75

The lenses are about 1. 5 to 2. 0 m long and 0. 3 to 0. 4 m thick. They display a well-expressed cross-bedding formed by laminae of a somewhat different granulometric composition. The visible thickness of these channel deposits is about 2 m.

2. The oxbow alluvium is represented by dark-gray, light-weight horizontally stratified loam with thin lenses of plant detritus, up to 0. 005 m thick. This member carries numerous ice-wedge pseudomorphs attaining a considerable size. As a rule, they are filled with a dark-gray, somewhat smoky-blue loam. Upward bent laminae occur at the contact of "wedges" with the enclosing rock. A few pseudomorphs penetrate the channel deposits without causing any special changes in their stratification. This alluvium is about 2. 5 m thick.

A spore-pollen analysis of samples from the ox-bow alluvium has revealed their comparatively low spore and pollen content, which prevents the construction of a more detailed diagram. However, Table 1 shows that the flora has changed somewhat, as indicated by a decrease in the woody-plant pollen content and a corresponding increase in grass pollen. The results of a paleocarpologic analysis generally agree with the spore-pollen analysis data. Identified among seeds from the ox-bow alluvium are the following: Larix sp., Picea sp., Alnus sp., Salix sp., Potamogeton pectinatum L., P. sp. Polygonum amphibium L., Rumex sp., Carex rostrata Stok., C. sp., Eriophorum vaginatum L., Scirpus sp., Eleocharis sp., Myosotis palustris (L.) Hill., Comarum palustris L., Scutellaria sp., Ranunculus sp., Menyanthes trifoliata L. Two species of mosses, apparently Sphagnum (?), have also been identified. Predominant in this list are seeds of grasses, mostly hydrophilic, which were growing in depressed marshy areas of the floodplain. The presence of the Picea and Larix seeds suggests that higher elevations of the valley were overgrown by a coniferous forest.

As shown by the spore-pollen analysis, this alluvial section was formed under comparatively more rigorous climatic conditions which subsequently determined the development of the Taz glaciation. This section appear to characterize one of the types of younger segments of the Messovsk-Shirtinsk Yenisey floodplain. Paleobotanically, it probably is a continuation of the preceding section.

These data fairly convincingly expose as unsubstantiated the view of the Taz west Siberian glaciation as a stage of the Samarian. The analyses suggest that climatic conditions of at least one of the last stages of formation of the Messovsk-Shirtinsk intermorainal alluvium were similar to that of the present; in any event, they were no more rigorous than at the onset of the Holocene. At the same time, these facts militate

against the opinion based on scattered spore-pollen analyses of samples from the Messovsk-Shirtinsk alluvium, that mostly open tundra and forest-tundra landscapes prevailed in the Yenisey region at that time [1, 2]. These vegetation types are associated only with periglacial regions, in this province [1].

On the basis of the above exposition, the buried Messovsk-Shirtinsk alluvium may be regarded as interglacial deposits.

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REVIEWS AND DISCUSSIONS[1]

ON THE REVIEW OF "STRUCTURE AND HISTORY OF DEVELOPMENT OF THE CASPIAN TROUGH AND ADJACENT PROVINCES IN CONNECTION WITH OIL AND GAS PROSPECTS" BY G. YE. -A. AYZENSHTADT, S. N. KOLTYPIN, AND N. K. TRIFONOV[1]

by

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Izvestiya of the Academy of Sciences, USSR, Geologic Series, No. 4, 1959, carries a review of the book cited in the title, by G. Ye. Ayzenshtadt, S. N. Koltypin, and N. K. Trifonov.

Discussion and constructive criticism are undoubtedly useful and helpful in the correct solution of a number of scientific problems. However, this approach is not used by these three authors: their data and conclusions are in contradiction to the facts; for that reason they provoke a legitimate protest and a response.

First of all, the reviewers strive to demonstrate that the feasibility of applying structural-facies analysis was known prior to the publication of our monograph. We cannot agree with that. It can be stated quite definitely that this monograph [7] indeed offers the first comprehensive substantiation of the applicability of this method in a salt-dome province. What is more important, this has been accomplished for the first time in the preparation of facies and isopach maps for the entire Caspian trough.

The book cites specific examples of the feasibility of application of cross sections of salt-dome structures; inquires into the cause of changes in thickness of overburden over salt domes, and into the ways of reconstructing full sections; shows the importance of regional erosional surfaces, determined by the changes in general oscillatory movements of the crust; reveals general regularities in the development of salt domes with relation to sedimentary and tectonic conditions; and exposes the lack of justification for differentiating interdomal facies and sections. This is understandable to any diligent and objective reader. The book also takes into account the opinions of other authors on this subject, including those of G. Ye. Ayzenshtadt (pages 20 and 30), which is more than the reviewers, especially G. Ye. Ayzenshtadt, have done for earlier students (e. g., V. Ya. Avrov, M. P. Kazakov, P. Ye. Kharitonov, and others).

Referring to page 23, the review objects to the premise of consistency in the thickness of individual units over long distances. The fact is that page 23 deals with the consistency not on a regional scale but rather for interdomal zones. There is no need to prove the well-known fact that individual Mesozoic units undergo considerable change in thickness within the Caspian trough. The example cited by the reviewers is unnecessary. A glance at the isopach maps (Appendices 5-17) is enough. These maps also show that there is no progressive thickening from the eastern boundary to the central southern parts of the Caspian trough, contrary to the oversimplified conceptions of the reviewers.

The reviewers are perplexed that the description of the section begins with the Upper Carboniferous; they hint at the authors' ignorance of older deposits within the south Emba positive gravity anomaly. As a matter of fact, such data are given in the section on tectonics (page 274). There is no need to prove (as the reviewers themselves know) that the data extant are inadequate for the construction of isopach and facies maps for older deposits in the Caspian trough, and even for individual provinces, except from the Upper Carboniferous up, which is exactly what has been done in the monograph.

In the discussion of Artinskian and Kungurian deposits of the south Emba section, there is a reference to a borehole which, according to the reviewers, "has allegedly penetrated the

[1] Po povodu retsenzii G. Ye.-A. Ayzenshtadta, S.N. Koltypina i N.K. Trifonova na knigu "Tektonicheskoye stroyeniye i istoriya razvitiya Prikaspiyskoy vpadiny i smezhnykh oblastey v svyazi s voprosami neftegazonosnosti".

Kungurian below the Permian and Triassic; as a matter of fact, stratigraphic test No. 2 (obviously meant in the book) stopped in the Permian or Triassic. The Kungurian was not reached there, and could not have been reached because it lies at a depth of about 4000 m at that point."

It so happens that stratigraphic test No. 5 rather than No. 2 is meant, and it did penetrate the Kungurian at 2306 to 2588 m, and the Artinskian below it. The reviewers are well aware of this but attempt to mislead the reader. A proof of this is the publication by one of them, G. Ye.-A. Ayzenshtadt [3], in which Kungurian deposits penetrated by borehole No. 5 are described on page 19. The same thing is mentioned quite distinctly in a book by M. P. Kazakov et al [7], on page 273.

The reviewers' statement that the authors, in their description of Artinskian and Kungurian deposits, have utterly disregarded drilling data in Tugarakchan, in the southern part of the south Emba region is equally wrong. As a matter of fact, the book mentions it on pages 31, 41, 44, and 273.

The review gives enough attention to the problem of Permian and Triassic redbeds. First of all, a premise is advanced that the monograph puts the beginning of redbed deposition into Upper Permian, the time of formation of the Ufa redbeds. The reviewers voice their astonishment at the correlation of the Kungurian salt-bearing sequence, involved in the dome making, with the redbeds. The fact that they could arrive at such a conclusion is even more astonishing. It is clearly stated in the book (pages 50-51) that the authors, in opposition to other views, regard the Ufa redbeds as an independent stratigraphic sequence above the Kungurian and part of the Lower Permian. Consequently, the reviewers' efforts to convince themselves and the others that Lower Permian intervals "have not been penetrated, as yet, anywhere in interdomal zones, and there is no reason for their assignment fully to redbeds." are in vain.

By the same token, the inconsistency of the reviewers' arguments on the error in our paleogeographic maps is obvious. Even more astonishing is the reviewers' assertion that in isolating the redbed complex, we did not consider the gray deposits, limestones, etc.; therefore, there is no substance in our designation of a single complex. It is obvious, however, that we speak of redbeds as a formation reflecting a definite and generally tectonically discrete stage of development. The book demonstrated the complex composition of the redbeds, differentiated individual marine intervals, the Kazanian and Tatarian deposits, and the elements of paleogeography. This is the true situation which the reviewers have overlooked.

A thinner Permian-Triassic zone in the central part of the Caspian trough has been designated on the basis of general regularities in the distribution of thicknesses and structural relations within the entire Mesozoic-Cenozoic section. Foredeep zones of greater thicknesses are quite definite not only for the Permian and Triassic but for a subsequent period as well. This alone is sufficient basis for the representation of linked zones of relatively decelerated subsidence and sedimentation processes. Our differentiation of such zones finds support also in a progressive thinning toward the crests of the uplifts. This is the basis for our representation of the central areas of thinning, rather than the position of maximum thickness as the reviewers strive to show.

We cannot pass by the remark on the description of Jurassic deposits, and especially the conclusion that "it is difficult to discover here any new ideas and representations." It is well known that many geologists participated in the study of Jurassic deposits in individual areas of the Caspian region. Each of them has made his contribution. Our introductory chapter alone (pages 63-67) mentions up to thirty students of the Jurassic. All of them, however, dealt with individual intervals of the Jurassic section or with individual areas of the Caspian region. The very fact that the monograph presents for the first time a correlation of all Jurassic sections for the entire Caspian trough and adjacent areas of Mangyshlak, Astrakhan steppes, lower Volga, Obshchiy Syrt, etc., exposes the reviewers' assertions.

However, our main contribution to the geology of the Caspian trough is not that but the isopach and facies maps for the whole Caspian trough and adjacent provinces. These maps afford a means of following in definite detail and stage-by-stage the history of tectonic development of such a vast province.

It is not a secret that only two sets of isopach and facies maps of the Jurassic of the Caspian trough have been published up to the present, by two different groups of authors: that of G. Ye.-A. Ayzenshtadt [2] and the one by M. P. Kazakov [7]. A comparison of the two sets exposes the fallacy of the reviewers' assertion on the lack of new ideas and new representations, in this monograph. First of all, F. Ye. Ayzenshtadt's maps illustrate a small area of the Caspian region, between Gur'yevo and the Emba mouth, while our maps cover the entire Caspian trough and even go beyond it. Furthermore, unlike G. Ye. Ayzenshtadt, we describe all of the Jurassic and its subdivisions, rather than the Middle Jurassic alone and we consider both the facies and thickness of the Jurassic rather than the thickness alone. It goes without saying that this enhances the value and the graphic quality of our

maps as a means of evaluating the geologic features of that region. The main difference, however, lies in the very content of the maps. Those of G. Ye. Ayzenshtadt are devoid of any structural representation. They only show a gradual and monotonous thickening of individual Jurassic units, to the south. Our monograph, on the other hand, uses a larger quantity of data in representing a number of structures in the same area, such as the Novobogatinsk and Sagiz uplifts, the Gur'yevo and Priemba (near-Emba) troughs, etc. Does this not constitute a new contribution to the Caspian regional geology, a fact which has escaped the three reviewers?

What has been said of the Jurassic is true for the other facies and isopach maps which add to the knowledge of structure and geologic history of the Caspian trough. This is also true for our tectonic map of the entire Caspian trough and adjacent provinces. Like the other maps, it is original with us.

Another novelty and originality of our work is that it presents type sections for individual structural basins within the Caspian trough, along with their descriptions. The voluminous material used by us was thoroughly digested. A subdivision of Upper Cretaceous deposits by stages is given, especially for the west half of the Caspian trough; the Cenomanian is described for the entire trough; Lower Cretaceous, Jurassic, and Tertiary sections have been refined for many Caspian areas; full sections are reconstructed in the isopach maps, by adding the missing beds; and other corrections and refinements have been done. All that could have been discovered by the reviewers, without any difficulty.

To continue: the reviewers note certain inaccuracies in the distribution of the Paleogene in the lower Ural course, in the representation of facies in the Santonian and Campanian maps, etc. This criticism is based on later data, not available for the 1955 maps.

The reviewers concentrate on field data used as a basis for our facies and isopach maps. They state that "the thicknesses of various stratigraphic units are misrepresented by the authors, in many instances." They cite five such instances in support of their assertion. It is quite obvious to any geologist that this is not enough to condemn material obtained from a study of 6211 locations and used in the construction of our facies and isopach maps. However, even these objections are not supported by facts.

For example, the reviewers state that the thickness of Albian deposits north of latitude 47° (in the south Koshkar area) is 460 to 490 m rather than 350 to 380 m. Without getting into historic detail, we refer the reader to the recent work of V. S. Dneprov [5], which presents a cross-section of the south Koshkar in Figure 21, drawn, incidentally, by G. Ye. Ayzenshtadt. The eight boreholes of that cross-section show the true thickness of Albian-Cenomanian deposits as 360-370 m. The same thicknesses are given by V. S. Denprov for other adjacent areas.

The reviewers further state that maximum Neocomian thicknesses in the Karaton are over 520 to 530 m rather than 440 to 480 m as given in our book. This statement, too, is contradicted by the data of other authors. For example, V. S. Dneprov [5] cites the following data for the Karaton Neocomian: the pelecypod formation is 78 to 85 m thick; Hauterivian arenaceous-argillaceous formation, 45 m; Barremian sandy unit, 35 to 42 m; and Barremian motley formation, 155 to 170 m. Thus, according to the most recent data, the maximum true thickness of the Neocomian in the Karaton area is 342 m, and not 520 to 530 m as stated by the reviewers. This is the Neocomian thickness which we give for that area; according to our data, it is 440 to 480 m in areas to the south, which is 60 to 70 m less than given in the review. These discrepancies are due to the different interpretation of the Aptian, whose thickness for the Karaton area has been assumed to be 60 m thicker; this coincides with Yu. P. Nikitina's data [11].

With regard to the reviewers' observation on the discrepancy in the thickness of the Maastrichtian, it can be said that it is due to the indefinite Campanian-Maastrichtian boundary. The total Campanian-Maastrichtian thickness, as given in our book, does not reveal any discrepancy. We give it as 316 m; it is 320 m for the Tentyaksor area, as given by V. S. Denprov [5] and cited by the reviewers; it is 320 m in the G. Ye. Ayzenshtadt cross-sections; and 340 m as given by S. N. Koltypin [9]. There is no discrepancy in that.

The same is true for the thickness of the Karaton Upper Cretaceous. It is readily seen from our facies and isopach maps for Upper Cretaceous stages (Appendices 13-19) that our assumed thickness of the Karaton Upper Cretaceous is 544 m. The review gives the same figure of 540 to 550 m. The Upper Cretaceous isopach map (Appendix 19) for that area gives a thickness of 439 m, without the Cenomanian which is included in the Lower Cretaceous section. The same thickness for post-Cenomanian Cretaceous deposits is given by V. S. Denprov. In his work, he cites the following thicknesses for individual Upper Cretaceous units: Turonian, 95 m; Santonian, 40 to 60 m; Campanian, 120 m; Maastrichtian, 125 m; and Danian, 40 m. According to him, the total thickness of post-Cenomanian deposits is also 420 to 440 m. Consequently, here, too, the reviewers' assertions are erroneous.

Great confusion is caused by them in the

determination of thicknesses for individual stages and for an entire division of the Upper Cretaceous of Mangyshlak. Without considering every stratigraphic unit, that would take too much space, we only take up the reviewers' statement to the effect that "total thickness of the Mangyshlak Upper Cretaceous is known to reach 800 m." Let us look at the facts.

The most complete information on the entire Mangyshlak area has been ompiled by the All-Union Aerogeological Trust geologists who have conducted comprehensive geologic studies on a high scientific and technical level for a number of years, by means of drilling and by applying the latest methods of geologic mapping. The results of this work, after verification and approval by the geologic fraternity were published in 1956 as individual sheets of the State Geologic Map. This work has reflected the latest data on the Mangyshlak Upper Cretaceous deposits.

For the western part of Mangyshlak, the Tyub-Karagan Peninsula, L. F. Volchagurskiy and A. L. Yanshin determined the Cenomanian thickness to be 2. 5 to 53 m; Senonian-Turonian, 130 to 241 m; and Danian, 3 to 10 m. The total Upper Cretaceous thickness is 135. 5 to 304 m. According to T. P. Markova and A. L. Yanshin, the Cenomanian of the Karatushik area is 50 to 120 m thick; Turonian, 15 to 23 m; Senonian and Danian, 250 to 300 m. The total Upper Cretaceous thickness is 315 to 443 m. For the central areas of Mangyshlak, A. Ye. Shlezinger and A. L. Yanshin give a Cenomanian thickness of 30 to 70 m; Turonian, 4 to 30 m; Senonian, up to 390 m; and Danian, up to 10 m. The total Upper Cretaceous thickness here is 434 to 500 m. I. S. Pleshcheyev and A. L. Yanshin determined the following thicknesses for the eastern Mangyshlak region: Cenomanian, 30 to 40 m; Turonian, 5 to 23 m; Senonian, 130 to 291 m; and Danian, 5 to 65 m. The total Upper Cretaceous is 170 to 419 m thick.

These data wholly invalidate the reviewers' assertions. In Mangyshlak, at least within the area described in the monograph, there is not a single place where the Upper Cretaceous is 800 m thick, as the reviewers want to have it.

Incidentally, these data show up the lack of substance in another assertion—that we have not taken into consideration the latest data by the All-Union Aerogeologic Trust and the All-Union Petroleum Geologic-Exploration Institute. It is clear from the above exposition and from the numerous references in our text that the results of study by the All-Union Aerogeologic Trust have been used extensively. The data of other students were also used, including words by geologists of the All-Union Petroleum Geologic Exploration Institute, except for those results which contradict the geologic facts; this includes the conclusions by G. Ye. Ayzenshtadt, S. N. Koltypin, N. K. Trifonov, N. V. Nevolin, and some other geologists.

The reviewers ascribe to us information we do not convey in our book. For examples they point out that the thickness allegedly given in the book for the Mangyshlak Danian is 80 m while it is in fact 130 m. As a matter of fact, our distribution map for Danian facies and thicknesses (appendis 18) east of Kochak Bay gives 90 m for the Danian, with 120 m in the area of the Sary-Tash pier. In their argument against the monograph's authors on the thickness of the Apsheronian stage in the Novobogatinsk area, the reviewers conclude that "seismic data fully refute the monograph's authors concepts of any uplift in that area." Now, our facies and isopach map of Apsheronian deposits (appendix 22) does not show any uplift in the Novobogatinsk area, because there was no such uplift either in the Apsheronian or the Akchagylian. This is clearly stated in our book.

There are no certain data on the great thickness of Quaternary deposits in that area, either for the Apsheronian or Akchagylian, and not just for he Apsheronian alone as the review has it. From seismic studies, the thickness of these deposits has been determined to be 2000 to 2500 m and even 3500 m. Such large discrepancies show that these seismic determinations of thickness are not reliable and need additional verification. Nor are there definite paleontologic data corroborated by drilling, for describing the sequence which is 1000 m thick and over. It should be noted that deep drilling data were not available at the time of processing the monograph material. Moreover, the Neogene thickness could have been overestimated because of the dip. It is quite obvious that reliable data on this subject are still lacking.

The reviewers' observation on the separation "of two different lithologic complexes in Middle Jurassic deposits of south Emba, shale (the maritime part of the area between Gur'yevo and Dossor, Karaton and Kul'sary) and coal-bearing shale (the remaining part of the south Emba area)" is without justification. There is no mention of such complexes, either in the text or on the maps. Developed in those areas (appendix 6) is an arenaceous-argillaceous coal-bearing sequence and an argillaceous sequence with intercalations of brown, sooty coal.

The reviewers also tax us with failure to show salt domes in our cross-sections of the Caspian trough (appendix 32). The fact is that 12 domes are shown in the Artesian-Kamelik cross-section; 16 in the Saratov-Aktyubinsk section; and 19 in the Krasnoarmeysk-Terektysay section. A total of 68 different salt domes are shown in appendix 12.

These examples show up the nature of the reviewers' "critical observations."

Their deliberations on "the south Emba platform uplift" are especially noteworthy because this subject, in addition to its academic interest, radically affects the exploration for oil and gas.

In noting that the monograph's authors are inclined to assume the presence of Hercinian folding in the southern part of this province, the reviewers state that "some 3 or 4 years have passed since the writing of this monograph without any convincing evidence of folding directly in the area of the south Emba positive gravity anomaly having been uncovered by deep drilling." It so happens, however, that some ten deep test holes in that area have uncovered dislocated and metamorphosed Upper Paleozoic deposits, of which our critics should be aware. We regard the south Emba uplift as a structural zone located mostly within the geosynclinal slope of a foredeep. In our section on tectonics, there is no mention of a direct connection between the south Emba and the Chushka-Kul'sk positive gravity anomalies. On the contrary, it is stated on page 262 that the first has been displaced to the northwest, parallel to the second.

In voicing their objections to our structural interpretation of the southern fringe of the Russian platform, the reviewers refer to our allegedly "erroneous data on the thickness of the Lower Carboniferous (over 2000 m) and the Carboniferous together as over 2500 m". They believe that the total Carboniferous thickness here does not exceed 2000 m. It should be noted, first of all, that figures of 2000 and 2500 m are not fundamental in denying the presence of typical platform Carboniferous sediments within the south Emba gravity anomaly. At the same time, the 2500 m figure is closer to the true one than that given by the reviewers. Indeed, borehole No. 2-a penetrated 229 m into the Gzhel'sk stage, while borehole No. 3 penetrated 193 m into the Kasimovsk stage. Therefore, the thickness of Upper Carboniferous penetrated, far from the total, is no less than 422 m. Borehole No. 3 has penetrated the following Middle Carboniferous units: the Myachkovo, 120 m; Podol'sk, 289 m; Kashira, 56 m; and Vereya, 41 m. The thickness of the Middle Carboniferous is therefore no less than 490 m. Borehole No. 3 has also penetrated the following Lower Carboniferous units: Steshevsk, 114 m; Mikhaylovsk, 108 m; Aleksinsk, 203 m; and 41 m of the Tula unit. Borehole No. 4 has penetrated 760 m of a coal-bearing formation and 108 m of the Chernyshinsk unit; borehole No. 7 has penetrated 95 m of the Likhvinka horizon. The established, obviously incomplete thickness of the Lower Carboniferous in text holes is 1429 m. The total drilled thickness of the Carboniferous, far from the total, is at least 2341 m. Its total thickness undoubtedly is considerably over 2500 m. These are well-known facts.

However, the nature of the south Emba uplift is determined not by the upper Paleozoic thickness alone. The fact that this uplift is not a platform structure is attested to by a collection of geologic and geophysical data discussed in detail on pages 272-275 of our book and evidently overlooked by the reviewers. At the present time, a number of supplementary data support the structure of the southeastern fringe of the Russian platform as given on our tectonic map.

Seismic study has uncovered a number of anticlinal structures aligned along the positive gravity anomaly in Paleozoic deposits of the south Emba zone. Best expressed among them are the Sargamys, Tugarakchan, Torosay, and Diyarsk structures. Paleozoic deposits plunge steeply to the northwest, toward the Caspian trough. This plunge is step-by-step and is complicated by faulting. A number of individual linear uplifts of the type of broken up structures on the geosynclinal slope of foredeeps are present here; some of them are reflected in Mesozoic rocks. Those are inherited structures. In other words, the picture here is the same as that observed in the Aktyuba Ural region and areas to the north.

Finally, the problem of structural features in this region has been solved once and for all and unequivocally by specific sections obtained in recent deep exploration drilling in the south Emba zone. North of there, tests number 5 and 1-a have uncovered Artinskian and Kungurian deposits in no way different from those in the Akhtuba Ural region where they have always been regarded as typical foredeep deposits. In addition, the same regularity as in the Aktyuba Ural region has been observed for the Kungurian facies distribution in the south Emba; a gradual change from a terrigenous-sulfate sequence with intercalation of carbonate rocks to a sulfate sequence with salt beds, and then to a salt section, takes place on the geosynclinal slope of the foredeep toward its axis. This regularity is especially well presented on our Kungurian facies and isopach map (appendix 3).

In the central part of the south Emba zone, tests number 3, 4, 7, 10 and 11 penetrated Carboniferous and Devonian deposits with a predominance of coarse-clastic terrigenous sediments with conglomerates, many meters thick, of metamorphic and siliceous rocks. The rocks themselves are very dense and dislocated. Devonian beds dipping up to 45 or 55° have been observed in borehole No. 7, with 80° and even 90° dips in numbers 10 and 11. Such deposits cannot be regarded as platform formations.

These facts are so obvious that a number of conjectures have been voiced recently that the Uralian folded system may veer southwest and that it is possible to assume the presence of a Hercinian foredeep and its association with the south Emba uplift. Such views are set forth in

works of E. E. Fotiadi [12], P. Ya. Avrov [1], M. V. Muratov [10], V. Ye. Khain [13], Ya. S. Eventov [14], and A. K. Zamarenov et al [6]. In the latest work of R. G. Gavretskiy and A. L. Yanshin [4], their structural map of the Kokpektin massif shows the South Ural foredeep considerably to the south of it and trending to the southwest.

The reason for our detailed consideration of the structure of the south Emba maximum is its practical aspect. It is well known that, beginning with 1948 and at the recommendation of G. Ye. Ayzenshtadt, S. N. Koltypin, N. K. Trofimov, V. S. Dneprov, and other members of the VNIGRI who have long been the guiding inspiration of petroleum geology in the Emba, the Kazakhstanneft' Combine has been conducting a fruitless search for Paleozoic oil in the south Emba zone. It is quite obvious that such exploration, based on erroneous concepts of these geologists on the "south Emba platform uplift in the Paleozoic," could not have achieved and did not achieve positive results. Dense upper Paleozoic metamorphosed and dislocated rocks cannot and do not carry industrial deposits of oil and gas.

The above-discussed critical observations of the reviewers show a total lack of justification. G. Ye. Ayzenshtadt, S. N. Koltypin, and N. K. Trifonov either did not get acquainted with the content of our book or else they are not quite familiar with facts of the geology of the entire Caspian trough.

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ON THE POSITION OF BAKAL' SIDERITE IN ENCLOSING ROCKS[2,3]

by

N. V. Grinshteyn, Yu. A. Davydenko, O. P. Sergeyev, and V. A. Timeskov

Recently there have appeared a number of papers dealing in one way or another with the origin of the Bakal' deposits. Some of them are of no particular interest, while some others, including the Z. M. Starostina paper [22], bring to light new data.

This paper presents stratigraphic concepts on the ore-bearing Bakal' formation, of the last few years and at substantial variance with the M. I. Garan' ideas [2-5]. It also makes an interesting attempt to reconcile the concept of a sedimentary origin of siderite and the new data on the Bakal' stratigraphy. This is open to many fundamental objections. In addition, the paper contains, without giving any references, many important conclusions of other authors.

Thus, the Z. M. Starostina stratigraphic table of the Bakal' formation ([22], page 42, Table 1) presents an erroneous correlation with that of M. I. Garan'; in addition, it arbitrarily changes the names of his horizons [2] whose stratigraphic position has not yet been questioned. At the same time, this classification exhibits an amazing similarity with stratigraphic columns for the ore-bearing formation presented by O. P. Sergeyev (the Bakal' Geologic Exploration Party) and Yu. A. Davydenko (Irkutsk Mining-Metallurgical Institute) at the Bicentennial Scientific and Technical Bakal' Mines Conference. Horizons bak$_5$-bak$_9$ of the Z. M. Starostina classification correspond to O. P. Sergeyev's subdivisions of the Middle Bakal' horizon, not mentioned for some reason in Table 1. Z. M. Starostina's differentiation of the Bakal' formation and its horizon indexes are exactly the same as those of N. A. Davydenko, down to the names of some newly identified horizons.

The paper under review does not mention that from 1939 on, the problem of the wedging out of the Bakal' carbonate beds and their change to terrigenous facies has been brought up, time and again, by Z. M. Starostina's predecessors, both in publications and in reports of the Bakal' Mining-Exploration Party (GRP). Such an omission is understandable because Z. M. Starostina's conclusions on the subject are in sharp variance with the published data [3-5, 8, 18]. Important information on the association of Bakal' ores and dolomites [7, 10, 11, 13, 14-16], the zonation of carbonate beds (replacement of siderite by dolomite and then by limestone; compare [22 and 7, 14-16], and also reports of the Bakal' GRP) have been borrowed from other authors. The important point on the lateral extent of richest sideritic facies ([22], pp. 40, 58) is in effect also borrowed from Yu. A. Davydenko who determined the sublatitudinal trend of the Bakal' carbonate outcrops under a pre-Zigal'ga unconformity and the distribution in them of siderite deposits, near that unconformity surface ([7], pp. 81, 95-98). Z. M. Starostina's paper which contains a fairly broad description of the ore-bearing units does not carry a single reference to the published data on this subject ([2-5, 13]; reports of the Bakal' GRP for newly-identified horizons; [7], in part). The lack of space prevents citing smaller borrowings from publications and stored data.

Some references of Z. M. Starostina are not too reliable. For example, the constitution of the Bakal' units after M. I. Garan', as cited on p. 41, differs in many respects with the latter's work [2] cited in the paper. The error of M. I. Garan's stratigraphic scale for the same formation ([22, p. 41) has been noted not by the Bakal' GRP, but by Yu. A. Davydenko [7], etc.

Z. M. Starostina ignores many important and well-established features of Bakal' geology. Thus, her paper does not consider the deep and regular pre-Zigal'ga erosion responsible for the absence of most of the Bakal' horizons [7, 17, 18]. Shrouded in silence is the considerable degree of consistency in the Bakal' horizons; the wide distribution of hydrothermally altered rocks; the lack of stratigraphic controls for ore-making [7], etc.

Z. M. Starostina's claim on the priority of her ore-content maps for individual units (Figures 1, 4, 6, 7) is not just: the Bakal' GRP has been working on that since 1957.

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[2] O polozhenii Bakal'skikh sideritov vo vmeshchayushchikh porodakh.

[3] Review of the Z. M. Starostina paper, "Distribution Conditions of Siderite Ores in the Enclosing Rocks of the Bakal' Group Ore Deposits (South Urals). Izv. Akad. Nauk SSSR, ser. geol., No. 7, 1959.

The data of Z. M. Starostina are wrong in many respects; they obscure or distort the true geologic relationships. These errors are caused by a disregard for the work of her predecessors and mostly by a wrong correlation of sections, as well as by the lack of realization of the complex tectonics of the ore body. All this naturally has found its reflection in the illustrations which are commonly far from the truth. In order of exposition in the paper under review, the most glaring errors of fact follow:

It should have been indicated on p. 43 that brown iron ores (Nizhnebakal' ore deposit) in the Makarovsk shale[4] (bak_2) are genetically related to a Mesozoic oxidized zone [9, 20] and have nothing to do with the Bakal' siderite.

The presence of magnesite is erroneously associated with the Berezovsk horizon (bak_2) (p. 43). Also, there is no good reason for assuming an enrichment of the Berezovsk carbonate ores in terrigenous material, to the south, and its replacement by an argillaceous facies, in the same direction (p. 46). The consistency in the thickness of the Bakal' section [7], the presence in it of stratigraphic breaks, and other data, suggest, according to Yu. A. Davydenko, an angular unconformity at the base of the overlying Irkuskan shale as a reason for the disappearance of the Berezovsk horizon in the southern part of the ore field.

The Lower Bakal' horizon (bak_4) is described incorrectly (pp. 46-49). According to Z. M. Starostina, its thickness is 160 and even 185 m ([22], p. 48), while in fact it does not exceed 120 m. The significance of shale intercalations generally not typical of this horizon is also overestimated; it appears that the overlying shale and (bak_5) carbonate rocks have been included in this interval. Ore deposits of the Krepkaya and Okhryanaya hollows are associated with Lower Bakal' dolomite rather than with shale as assumed by Z. M. Starostina (p. 49). The nature of facies changes and the reasons for the fluctuation in thickness of the Lower Bakal' horizon is important in the solution of problems posed in this paper. However, the replacement of carbonate rocks by argillaceous rocks, mentioned by Z. M. Starostina (p. 48) has not been observed by anybody else for the simple reason that the Lower Bakal' horizon is very consistent. Thus, according to Yu. A. Davydenko, two thin layers of stromatolithic dolomite (a few meters thick) at the base of this unit persist for over 3 km from the south to the north (from Irkuskan to the northern part of Bulandikha Mountain) without any evidence of wedging out. The considerable fluctuations in the thickness of this unit, specifically its abrupt thinning in the Ivanovskoye and Aleksandrovskoye deposits as well as in the northern part of the central Irkuskan quarry, is related, according to the same author, to a stratigraphic break at the base of this unit (bak_5). Incidentally, this stratigraphic unit, the one subject to substantial facies changes has not been described in the Z. M. Starostina paper.

The stromatolithic unit (bak_6) is also marked by its consistency. Its thinning and disappearance in the southern part of the ore field are connected with the pre-Zigal'ga erosion rather than with a facies replacement of carbonate rocks or their wedging out, as Z. M. Starostina informs us (p. 50). This, by the way, is clear from her own cross-section ([22], Fig. 3).

The next higher carbonate unit (bak_8), unfortunately named limestone (p. 50), is virtually not described. Besides the limestone, it contains dolomite and siderite; it is marked by a consistent thickness of 70 to 80 m, thinning to the south and falling out of the section because of the same pre-Zigal'ga erosion. The reference to its carbonate rocks being replaced in the south by shale (p. 50) has no relation to reality.

There also are errors in the description of the last, the Upper Bakal' (bak_{10}), carbonate member of the ore-bearing formation. A detailed section of this unit has been published recently [7]. We only note here that its thickness is very consistent and does not exceed a hundred meters (on p. 54, Z. M. Starostina gives 120 to 130 and even 200 m). The thinning of this member and its disappearance, to the south, are due to the pre-Zigal'ga erosion [7]; this, incidentally, is excellently illustrated by Z. M. Starostina herself, in her cross-sections, Figures 8 and 9. The structure of this member differentiated in detail, is very consistent [7] and Z. M. Starostina's data on its facies inconsistency (pp. 52 and 54) are erroneous. Also erroneous is a reference to the association of iron ores in the southern part of the Ob"yedinennoye deposit with shale (p. 52).

* * * * *

The following statements can be made on the basis of established facts:

1. Carbonate units of the Bakal' formation thin out and disappear from the ore field section from north to south. This phenomenon is not connected with a natural wedging out of carbonate rocks or with their replacement by terrigenous facies but rather with a pre-Zigal'ga erosion increasing in magnitude to the south and affecting all but the two lower members of the Bakal' formation. The outcrops below the eroded beds have a sublatitudinal trend [7]. The causes for wedging out of the Berezovsk unit are not clear. They appear to be related to an angular unconformity within the ore-bearing formation.

[4] Here and in the following exposition, the Bakal' horizon indexes are those of Z. M. Starostina [22].

2. Within the ore field, the facies changes in the Bakal' formation are very slight, being expressed mostly in smoothly gradual changes in the elements of the section, perceptible only over considerable distances. Even one-meter thick layers are traceable, as a rule, throughout the ore-bearing area, as far as the pre-Zigal'ga erosion. There are no changes of entire carbonate units or sizable portions of them into argillaceous formations.

3. According to all data, the amount of terrigenous material in any carbonate member of the Bakal' formation does not substantially change throughout the ore field. It is reasonable to assume, therefore, that the same or similar facies conditions prevailed throughout this area during the formation of these units. There are no latitudinally trending zones, including those enriched in siderite, in the Bakal' area.

4. The Bakal' siderite and the alteration products, oxidized ores, occur exclusively in carbonate beds, gravitating, according to O. P. Sergeyev [21], to rocks the least contaminated by terrigenous additions. Brown iron ore in shale (the Nizhnebakal'sk deposit, [9, 20]; and possibly some of the northwestern Irkuskan ores, 1) are genetically related to a Mesozoic weathered zone rather than to the siderite. Because of that, the Z. M. Starostina concepts on the sideritic nature of the argillaceous facies are utterly groundless.

5. Siderite alone borders on magnesium-enriched varieties of carbonate rocks: dolomites and the considerably less common (in the lower Bakal' member) magnesite. A zonal replacement of siderite by dolomite and of the latter by limestone [7], from the south to the north, is quite conspicuous in the ore field. However, this rock alteration is not to be related to a facies change, inasmuch as any facies association of siderite with dolomite is absent within the carbonate beds.

6. Both siderite and dolomite replace carbonate beds regardless of origin. Dolomite and the ores occur in beds made up completely of stromatoliths, in the so-called "vermicular formations," usually markedly enriched in shale intercalations and inclusions, and in the most common varieties in the Bakal', poor in terrigenous material and without any trace of organogic textures, etc. What is more, the contacts with ore dolomite and with limestone cross the facies boundaries. Various layers forming the carbonate beds pass from ore bodies to the dolomite zone and then to the limestone. In this process, the composition of the terrigenous layers remains unchanged while carbonate beds, usually preserving their textural and in places, structural features, are replaced by siderite in ore bodies, and by dolomite in the dolomitic zone, and finally pass into limestone layers beyond that zone.

7. It follows that there is no stratigraphic association of siderite. Under certain structural conditions, all carbonate beds and layers of the Bakal' formation without exception are ore-bearing [7]. The contacts of ores with dolomite and of dolomite with limestone cut the stratigraphic boundaries and commonly run across the bedding for several tens of meters (the Gayevskoye and Novobakal'skoye ore deposits).

8. A vast majority of the Bakal' iron-ore deposits occur at the contact of carbonate beds with a stratigraphically unconformable formation overlying them [6, 7, 12]. The base of the Zigal'ga quartzite truncates the Bakal' beds progressively from north to south. The intensity of hydrothermal phenomena affecting the formation is greater toward the erosion surface (i. e., to the south) [7]; limestone of the carbonate beds is replaced by dolomite and then by siderite which reach their maximum thickness at the quartzite contact. Inasmuch as the trend of carbonate beds beneath the erosional surface is sublatitudinal, this is the trend of the zones most enriched in iron.

* * * * *

It is quite obvious that information on the distribution of the Bakal' siderite in the enclosing rocks, as given in the paper under review [22], are so far from the true facts that it cannot serve as the basis for a correct genetic concept. Naturally, the forecasts made on the basis of Z. M. Starostina's genetic views ([22], p. 5) are also wrong. For example, they exclude from prospective areas, the one located in the Irkuskan-Bulandikha syncline, north of the stromatolithic and Lower Bakal' "zones", although it is here that a thick carbonate unit (bak_8) passes; this unit is ore-bearing in the Shikhansk ore site. On the other hand, it is quite useless to look for ores in the "main facies" south of those "zones," where an occurrence of even minor brown iron ores of the oxidized zone type (Nizhnebakal'sk) is impossible in shale below the thick cover of the Zigazino-Komarovsk and Zigal'ga formations.

The features of development of the Bakal' siderite, revealed in the last few years and discussed in part here, as well as its association with the unconformity between the Bakal' and Zigal'ga formations, and many other features of these deposits, rule out a sedimentary origin. The Bakal' ores are obviously epigenetic with relation to the enclosing rocks. It is not an accident that M. I. Garan', on outstanding authority on the Bakal', who has done much to promulgate the hypothesis of a sedimentary origin, now hesitates to choose between it and hydrothermal concepts [5]. It also is not an accident that L. V. Pustovalov [19] attempts to

revive the hypothesis of an infiltrational origin for the Bakal' siderite.

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THE "UPPER CAMBRIAN" ARCHAEOCYATHID-CORAL ASSEMBLAGE IN THE TANNU-OLA RANGE (TUVA)[5]

by

V. V. Menner, N. V. Pokrovskaya, and A. Yu. Rozanov

Up to now, Upper Cambrian deposits (metamorphic schists barren of organic remains) have been identified tentatively only in the northern and northwestern parts of Tuva, beyond the Tannu-Ola Range. For that reason, the communication by A. G. Vologdin in Doklady of AS U. S. S. R. (vol. 129, No. 3, 1959) on his finding of an Upper Cambrian Archaeocyathid-coral assemblage in the Tannu-Tuva range is of no small interest. Unfortunately, a careful study of his material casts doubt on his conclusions.

The rocks of Upper C mbrian age along Serlig River (south slope of the Tannu-Ola Range) were dated by A. G. Vologdin from his identification of organic remains (Figure 2) with Cambrophyllum problematicum Fritz et Howell, 1955 (Figure 1-a, b), a coral from the lower part of the Upper Cambrian of Montana. This species, having been described from a single specimen, does not contribute anything to a precise age determination. According to A. G. Vologdin, the similarity between the Tuva and North American forms is revealed "in the thickness of the corallite walls, in the shape of their cross-sections, and in their dimensions." Measurements of both specimens have shown, however, that the Serlig River form has walls not thicker than 0. 08 mm, with 0. 25 to 0. 5 mm for the Montana form; their diameter is 0. 2 to 0. 6 mm[6] and 0. 8 to 1. 2 mm, respectively. Their cross-sections too, have little in common. In the Fritz and Howell specimen, the corallites are polygonal, stretched across, less commonly rounded. In the Serlig River specimen, they are rounded. A. G. Vologdin notes that "The American Upper Cambrian coral has been described from wrongly oriented sections. For that reason, cross-sections of its corallites and a longitudinal section of its polypary do not give a true idea of the colony morphology." This, however, is not mentioned in the American work, and does not prevent the authors from comparing differently oriented sections to prove their similarity.

These data obviously militate against identifying the Serlig River organic remains as Cambrophyllum problematicum Fritz et Howell.

In structure, they are most reminiscent of the Lower Cambrian genus Bija Vologdin, 1932 (Figure 3) described by A. G. Vologdin from the Lebed' River limestone, the Altay, although they appear to belong to a new species Bija vologdini sp. nov.[7] which differs from the Bija sibirica Vol. in the size of its corallites and the thickness of their walls. It is pertinent to mention here that the ratio of the average diameter of corallites to the wall thickness for these species of genus Bija is 6. 0, while it is about 2. 5 for Cambrophyllum problematicum F. et H.

Along with Biji vologdini sp. nov., A. G. Vologdin notes Archaeocyathidae remains on Serlig River, typical of the Lower Cambrian Lena stage and classified as two new genera. It is these two archaeocyathids that should have been the main age-determination criterion.

The similarity of archaeocyathids and corals described in the A. G. Vologdin paper with typical Lower Cambrian forms common in the deposits from adjacent areas suggests rather a

[5] O "Verkhnekembriyskom" arkheotsiato-korallovom tsenoze khrebta Tannu-Ola (Tuva).

[6] A. G. Vologdin has 0.8 mm for the second figure.

[7] Genus named after A.G. Vologdin, an outstanding student of the Siberian Precambrian.

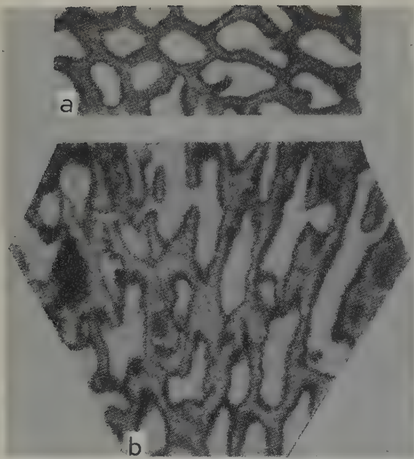

FIGURE 1-a. Cambrophyllum problematicum Fritz et Howell, 1955. Magnification 5 X; transverse section from the Fritz and Howel paper.
FIGURE 1-b. Same, longitudinal section; 5 X.

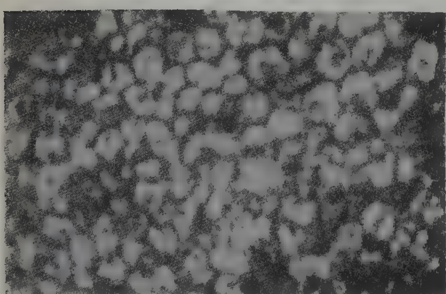

FIGURE 2. Bija vologdini sp. nov. (Cambrophyllum problematicum Vologd. 1959 non Fritz et Howell, 1956); 10 X.

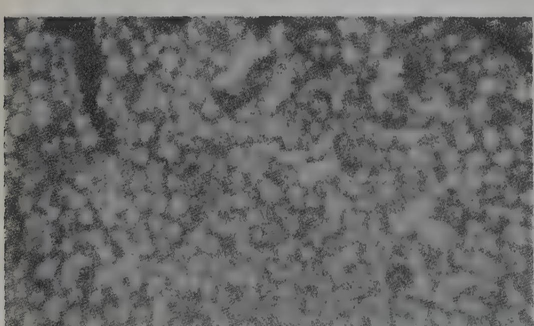

FIGURE 3. Bija sibirica Vologd. 1932, from A.G. Vologdin's "Archaeocyatidae of Siberia", issue 2.

Lower Cambrian age for the Serlig River rocks with these archaeocyathids and corals. According to an oral communication of O. K. Poletayeva, N. Ye. Chernysheva has identified Inouina sp., a form of the middle Lena stage of the Lower Cambrian, from specimens carrying the fauna described by A. G. Vologdin. An additional confirmation comes from material of the latest geologic surveying works according to which Serlig River cuts through Lower Cambrian rocks only. Unfortunately, the author does not indicate the exact locality for his specimens, which precludes locating them in the section.

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THE NOMENCLATURE OF EXTRUSIVE ROCKS[8]

by

S. N. Ivanov

Ye. K. Ustiyev begins his paper on the nomenclature for volcanic rocks with a brief historical review. He voices an opinion that a paleotypal aspect of extrusive rocks bespeaks only their older age. The author belittles the significance of those radical changes which W. Brëgger, F. Yu. Levinson-Lessing, and A. N. Zavaritskiy have introduced into the literature on the dual nomenclature of extrusive rocks. Despite the changed names for both groups of rocks ("paleotypal" and "cenotypal" for "paleovolcanic" and "neovolcanic") and perfectly

[8] Review of Ye. K. Ustiyev's paper of the same name in Izvestiya Akad. Nauk SSSR, ser. geol., No. 11, 1959.

ar exposition of the new meaning of the two ups, by those three scientists, especially A. N. Zavaritskiy, Ye. K. Ustiyev goes on follows: "It is well known (? --- S. I.) there are in modern petrography two quite erent principles of nomenclature for ex-sive rocks. In the first one . . . extrusives differentiated by their age into paleovolcanic neovolcanic, which corresponds under Mid-European conditions to pre-Mesozoic and t-Mesozoic formations" (p. 3; Underscoring e and below are the authors — S. I.). And in, "The A. N. Zavaritskiy system is based false premises of differences in the princi- (otherwise there would not have been any ed in working out two series of names) be-een extrusive rocks of different geologic ages"], p. 6).

Y. K. Ustiyev ignores the essence of the pre-ses of A. N. Zavaritskiy and his predecessors, ich is that change in the mineral composition volcanic rocks rather than age constitutes the sis for their classification.

At the end of his paper, Ye. K. Ustiyev states at the A. N. Zavaritskiy suggestions allows e application to this group, of such hitherto used terms as 'andesite-basalt porphyrite', achy-andesitic porphyrite', etc., i. e., it nders the entire system more flexible. Such ing the case, what is wrong with A. N. Zavar-skiy's system? If it provides a parallel no-enclature for both rock groups, the main and fact the only argument of Ye. K. Ustiyev for reform in the nomenclature falls through.[9]

In Ye. K. Ustiyev's opinion, the present dual ystem complicates and hampers the study of ose areas where both fresh and altered ex-usives are developed.[10] We cannot agree with at. Any detailed differentiation, based on ore numerous criteria for objects classified, more difficult; as a rule, it also is more aluable, and Ye. K. Ustiyev does not explain xactly what is the confusion in classifying olcanic rocks as cenotypal and paleotypal. Vhy is a map showing andesite and andesite orphyrite any clearer if the andesite porphy-ite is called simply andesite because of the emains of original features preserved in it? Obviously, the first method would convey more omplete and more correct information on the rea in question, while it is always possible to elect proper symbols to represent the fact hat both the fresh and the altered extrusives elong to the same formation or sequence.

One can agree with Ye. K. Ustiyev that the application of a dual nomenclature in areas of a wide development of transitional type extrusives, where it is necessary to represent the degree of their alteration, may complicate the work. Such complication may not be justified everywhere. But a petrographic nomenclature cannot be changed for a more convenient study of this or that region. This is ever so much more true because such a "convenience" may and does lead to where metamorphic changes escape our attention.

Of primary importance in the understanding of volcanic hearths is a study of individual stages of their evolution, including those where the magmatic sources produce hot metamorphosing solutions. This is underestimated by Ye. K. Ustiyev.

A great significance is attached now to metasomatic and metamorphic processes in the formation of many widely distributed rocks. The refusal to take into account greenstone and other metamorphic alterations, in naming the rocks, appears to be ill-timed.

It is well known that the formation of various industrial minerals is closely related to regional metasomatic and metamorphic processes. For example, ore deposits of a pyrite type (copper, polymetallic, etc.), which are of great economic importance, are always accompanied by regional greenstone alteration of the ore-enclosing volcanics (albitization, chloritization, etc.).

In our perusal of published data on pyrite ore deposits of the U. S. and Canada, we ran into difficulties precisely because the secondary alterations of volcanic rocks had not been reflected either on maps or in the brief descriptions.[11] The advantage of our petrographic nomenclature over the Anglo-American is very convincing, in this respect.

A correct understanding of the present aspect of extrusives and of the alterations they have undergone is essential not only in solving the problems of post-igneous mineral formation in its broadest sense, but also in the practical use of volcanic rocks for building and other industrial purposes.

Ye. K. Ustiyev proposes to designate rock alterations by certain adjectives: "chloritized and albitized dolerite" for diabase, and "albitized trachyte" for albitophyre. This recommendation does not simplify the petrographic

[9] Ye. K. Ustiyev's statement that "no one uses" the . N. Zavaritskiy system is not true.

[10] In his talk at the Yerevan Volcanologic Conference, e. K. Ustiyev again spoke on confusion arising from e use of a dual nomenclature for extrusive rocks.

[11] Canadian and American geologists give different names to the same paleotypical rock. For example, the same quartz keratophyres are called alaskite porphyry, quartz porphyry, sodium rhyolite, sodium rhyolite porphyry, and simply rhyolite and aporhyolite.

nomenclature; what is more, it is applicable only for initial stages of lava alteration. Furthermore, the introduction of a definitive adjective into the name of a rock, without which that rock name acquires a different meaning, is unacceptable because such a usage is open to the hazard of an unconscious omission of the definitive adjective for "brevity", thereby indeed leading to confusion. Such inadmissible "simplifications" of rock names unfortunately are not uncommon.[12]

While suggesting that special names for paleotypal rocks be abandoned, Ye. K. Ustiyev consents to make an exception for diabase, spilite, and keratophyre, whose formation reflects special conditions for magma flows. However, it is inconsistent not to include, for the same reason, "quartz keratophyre" as well, which is a full-flegded member of the spilite-keratophyre series. In retaining the names keratophyre and quartz keratophyre, while abandoning "albitophyre" and "quartz albitophyre", clean-cut petrographic criteria must be set up for an unmistakable differentiation of albitophyre and quartz albitophyre from keratophyre and quartz keratophyre.

The Ye. K. Ustiyev suggestion to call only those rocks formed at an early stage of evolution in geosynclinal provinces diabase, and to call all other diabase rocks, dolerite is hardly fortunate. It seems to me that preference should be given to those rock names inspired not by abstract concepts but by real and unquestionable petrographic features visible in any hand specimen or at least in any outcrop.

Ye. K. Ustiyev's simplified petrographic nomenclature would introduce very great difficulties in the mapping of Paleozoic and some other ancient volcanic provinces. Because of the greenstone and other alterations, exact determination of the original nature and name of a rock is commonly impossible. Suppose a rock carries feldspar incrustations and a partial y recrystallized groundmass of microlites of albite, abundant epidote, and chlorite. We now call such a rock porphyrite or feldspar porphyrite and we know that it was originally a basic lava. We cannot tell anything more of its original aspect. Even with a complete chemical analysis (which is not always possible), it is at times difficult to determine the cenotype of such a rock. That would require the certainty that no addition and leaching of chemical components has taken place in the process of alteration.

Again, what name should be given to a rock consisting of porphyritic phenocrysts of albite and a secondary groundmass of albite, quartz, and of an often variable amount of chlorite and epidote? In those instances where the porphyry phenocryst albite is secondary, such a rock should be called, strictly speaking, metamorphic. Usually, however, and with a very few exceptions, it is called "albitophyre". Very commonly, if not always, the origin of such a rock is unknown; the original rock could have been trachyte, andesite-dacite, or even andesite. How, then, are we to call such a rock in the Ye. K. Ustiyev nomenclature? Obviously, we cannot call it anything but metamorphic; any other name would be a matter of taste guided by various indirect criteria (if they are present) or else by sheer intuition. It is very probable, in this procedure, that some geologists would call it trachyte, some others albitized andesite, and still others, perhaps, dacite. Which one of them will be right and how are their maps to be correlated?

In accepting Ye. K. Ustiyev's premises, we thread a dangerous path of naming natural objects from their directly observable features and of lapsing into a nomenclature based on our individual and often unreliable ideas of their origin.

The poorly developed classification of paleotypal extrusives as compared with that for fresh lavas is not a result of the lack of attention. Such a situation prevails because their alteration precludes a more detailed differentiation on the basis of primary features.

A. N. Zavaritskiy, in his time, was very much disturbed by the practice prevailing in the Urals, of assigning without good reason but with much authority, the names keratophyre, porphyrite, and other paleotypal names to extrusive rocks. He published, in cooperation with B. I. Gon'shakova a special glossary of extrusive rocks [1]. The basic principle of that glossary, by no means obsolete even now, is that rocks are named by their observed features: mineral composition, structure, and conditions of occurrence. In noting the importance of the origin of rocks, A. N. Zavaritskiy stated at the same time, "To base oneself exclusively on concepts of the origin of a rock is to substitute a classification and systematics of concepts and ideas for those of objective facts. Therein lurks the danger of a preconceived approach to the study of an object, the danger of overlooking the essential and of overestimating the less important criteria" (p. 8).

In his glossary we find such terms as "greenstone diabase rock", "greenstone porphyritic rock", etc. This glossary has played a large part in bringing order into the Uralian rock nomenclature and in improving the quality of geologic maps, especially of those on a large scale.

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[12]Many field geologists, as stratigraphers and even geologists studying ore deposits, do not hesitate to designate quartz albitophyre as "albitophyre," although this is more erroneous than to call liparite "trachyte", because albitophyre originates in the albitization of andesite, as well.

The confusion would be unbelievable if, following Ye. K. Ustiyev's advice, on all geologic maps of the Urals with their preponderance of extrusive rocks, all paleotypal names had been changed to cenotypal names, according to the whim of individual map makers. I can only say that this would be a step backward.

Finally, the last argument of Ye. K. Ustiyev for substituting the Anglo-American nomenclature for the domestic one is to achieve international unity in that respect. To be sure, an international unity of terminology is useful and to be striven for, at a scarifice of one's own usage. It does not follow, however, that such an achievement is worth renouncing a more perfect system for a simplified one. The fact that the Anglo-American nomenclature for extrusive rocks is now adopted in many countries is not an argument for its universal recognition.

There have been examples of petrographers from countries not using paleotypal rock names realizing the inadquacy of their petrographic nomenclature and proposing specific names for altered rocks. I quote M. H. Battey, a well known English petrographer who has recently studied upper Paleozoic keratophyres of New Zealand. Having arrived at the conclusion that those rocks represent metamorphosed rhyolites, he states, "Although keratophyres are not the product of a special magma and do not often form an individual extrusive fraction, they do represent a facies of moderate metamorphism. For this reason, it is important to retain or them a special name setting them apart from rhyolites with a high-temperature mineralogy" ([2], p. 123).

In summing up, it can be stated that the retaining of individual names for extrusive paleotypal rocks is quite justified. Paleotypal volcanic rocks constitute a natural and true link between fresh igneous rocks (lavas) proper and metamorphic rocks which have lost their original mineral composition and much of their primary microstructure.

The boundary between paleotypal and properly igneous cenotypal rocks can be refined. A change from high-temperature plagioclase to the low-temperature, of sanidine to orthoclase, pigeonite to pyroxene with a large angle between the optic axes, the crystallization of glass, and some other clear evidence of an incipient change in the mineral composition, give an adequate basis for drawing such an arbitrary line.

According to A. N. Zavaritskiy, the boundary between paleotypal and metamorphic rocks is determined by the preservation in paleotypal extrusives of the main features of the original mineral composition and magmatic structure of the groundmass ([1], p. 11). This definition is very "strict" and it narrows considerably the paleotypal rock group. Considering the tendency, long since established in petrography, to explain many microstructures in paleotypal rocks as formed by metasomatic and metamorphic processes, it must be admitted that the entire group of paleotypal extrusives should gradually decrease in volume. However, such is not the case, because metamorphic rocks which have lost their original mineral composition but have preserved well their occurrence conditions, external aspect, and porphyritic texture, are also termed volcanic paleotypal rocks. Petrographers who work in provinces of Paleozoic and older volcanism are constantly confronted with rocks possessing such characteristics.

There is no proper name for such rocks as the non-basic, obviously originally volcanic albite porphyrite mentioned above. It if is named albite-quartz-chlorite-greenstone rock or albitophyre greenstone rock, the first name is too cumbersome and does not reflect the rock's geologic structural features (the aspect of and altered extrusive rock); in both instances, it is inconvenient to call "greenstone" a rock where secondary-colored chlorite and epidote are subordinate and are in places fully replaced by a light-colored mica. Such essentially metamorphic rocks perhaps should be called apoalbitophyres, and the corresponding strongly altered porphyrites, "apoporphyrites".

This method would be difficult to apply in evolving the name for a metamorphic rock originating from quartz albitophyre, quartz porphyry, and quartz keratophyre. The names for the latter are generally inconvenient; as stated above, they sometimes cause confusion. In those numerous examples, however, where the groundmass of such rocks has retained its main structural features, but where feldspar phenocrysts have undergone albitization while dark-colored ones have been chloritized, their classification is very difficult, if not impossible. It would be expedient to designate such rocks by a common name denoting their main and persisting feature, the quartz phenocrysts. It seems to me that they could be called "quartzphyres" with the corresponding metamorphic rock called "apoquartzphyre".

Should a successful nomenclature be hit upon for metamorphic rocks retaining definite volcanic structural features, and should such a nomenclature be adopted by our petrographers, the boundary between metamorphic and paleotypal volcanics would have shifted considerably in the direction of the volcanics. It is possible that such an eventuality would create conditions favorable for a "liquidation" of the dual nomenclature for extrusive rocks. Such an eventuality has not yet arrived.

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NOTES ON THE YE. K. USTIYEV PAPER, "THE NOMENCLATURE OF EXTRUSIVE ROCKS"[13]

by

V. I. Lebedinskiy

Izvestiya of the Academy of Sciences, Geologic Series, No. 11, 1959, carries a paper by Ye. K. Ustiyev, "The Nomenclature of Extrusive Rocks", which undoubtedly has attracted the attention of geologists working in many fields. This interest in this paper is due to the fact that Ye. K. Ustiyev has brought up an important topic on which there is no unanimity of opinion and in which there are many archaic terms. In addition, the author is a well known authority on petrography who has studied volcanism in the northeastern part of the U. S. S. R. for a long time.

The value of the two parts of this paper is uneven; part one gives an analysis of the reasons for the two nomenclatures of extrusive rocks, and of the evolution of petrographic terminology; in part two the author presents his reasons for rejecting the dual nomenclature.

We agree with Ye. K. Ustiyev's exposition of the history of nomenclature of extrusive rocks, where he correctly states that the development of a single-name and a double-name nomenclature took place in countries with different geologic histories. For that reason, rocks which geologists found in areas of ancient and new volcanism differed from one another. This, in turn, has led to different nomenclatures in Europe (double-name nomenclature) and in the two Americas (single-name nomenclature). Ye. K. Ustiyev is quite right in saying that even after W. Brügger had proposed, in 1894, to abandon the age principle in classifying extrusive rocks, but to retain and use the dual nomenclature for designating altered (apleotypal) and fresh (cenotypal) lavas, there was no grounds for a distinction between these two groups.

When, however, Ye. K. Ustiyev turns to the present status of the nomenclature of extrusive rocks and states that there are no reasonable criteria for paleotypal and cenotypal aspects, we cannot agree with that. In analyzing the views on the nomenclature of extrusive rocks of such outstanding Soviet petrographers as F. Yu. Levinson-Lessing and A. N. Zavaritskiy, who used the double-name nomenclature, Ye. K. Ustiyev omits for some reason M. A. Usov who inquired into the conditions under which extrusive rocks existed after their formation, depending on the geologic environment, and who has worked out a classification and nomenclature on that basis. M. A. Usov has demonstrated that the so-called state of preservation of a rock, i. e., what is called its cenotypal, paleotypal, or greenstone aspect, is not an attribute per se but is very closely related to its genesis and to the subsequent stages of its existence. These concepts of M. A. Usov, known as the theory of extrusive phases, should be appreciated as a geologic illustration of dialectic materialism applied to the relationship and mutual determination of natural phenomena.

In considering extrusives as formations consisting of metastable minerals which behave in different ways after their formation, M. A. Usov has designated three series of rocks: the primary phase (cenotypal), diagenetic (paleotypal), and greenstone. In modern terms, the first are formations in young and ancient platforms; the second are formations in fold zones, during their pre-inversion period; and the third, in fold zones with superimposed tectonic and igneous activities. It is indisputable, therefore, that rocks of about the same chemical composition but with different mineral, structural, and textural features and, what is very important, a different geologic history, should be assigned different names. In this connection, an analogy can be drawn with sedimentary petrography, where sediments (such as sand) have names different from those assigned to their descendent rocks (sandstone).

We have intentionally given so much space to M. A. Usov's concepts to emphasize the fact that for over 30 years there has been a view abroad which not only justified but, indeed, demanded the retention of a dual nomenclature for extrusives. The theory of extrusive phases has withstood the test of time, has not been subject to any substantial criticism, and is an achievement of Soviet geologic thought. As such, it must not be simply discarded. Of course, new data on the origin of some minerals and rocks call for some modification and refinement in theory of extrusive phases. It should be kept in mind that the decisive part in the formation of mineralogic features of, for example, keratopyres belongs not to regional metamorphism but rather to epimagmatic metasomatic phenomena. In determining the phase of an extrusive from the mineral composition data, the origin of metastable minerals (trondjemite, sanidine,

[13]Zamechaniya k stat'ye Ye. K. Ustiyeva "K voprosu o nomenklature effuzivnykh gornykh porod".

c.) which may occasionally be epimagmatic, must be carefully determined. This necessity of a more careful approach to the assigning of an extrusive rock to this or that phase does not mean, of course, that our concepts of changes in rock properties with geologic environment are inadequate. It indicates, rather, the complexity of natural processes affecting an extrusive rock subsequent to its formation.

It should be emphasized that such an historical-geologic approach to extrusives permits the utilization of their petrographic properties for a reconstruction of the geologic history of the area in which they occur. Thus, upon coming across cenotypal rocks in an area of distribution of the apleotype, we are justified in assuming the manifestation of another and younger igneous-tectonic cycle or some other special factor determining the appearance of rocks with a cenotypal aspect during the formation of paleotypal extrusives. For example, in an occurrence of cenotypal basalt among paleotypal spilite formed in submarine eruptions, the sharp difference in the degree of preservation of these rocks must not be overlooked; it must be explained. On the basis of the extrusive phases theory, it may be offered for discussion that the basalt is a younger rock formed in a different tectonic environment (a quieter one), or it is contemporaneous with the spilite but originated under special conditions (e. g., land eruptions).

The views of M. A. Usov on the history of extrusives are well known; they justify the use of a dual nomenclature. It is therfore difficult to understand why Ye. K. Ustiyev referred to M. A. Usov on a matter of secondary importance but never mentioned his theory of extrusive phases. The point is not that he has omitted any referetce to M. A. Usov's concepts which may now be formulated in a somewhat different way but that he has disregarded a geologic approach to extrusive rocks which requires the use of a double-name nomenclature as a matter of logical necessity. Ye. K. Ustiyev's suggestion to abandon the double-name nomenclature for a single-name one, while retaining the names of the cenotypal series has no reasonable foundation. It is in effect a return to outdated concepts of the early twentieth century; as such, it cannot command support.

It should be emphasized once more that the double-name versus single-name nomenclature is not a controversy about the convenience of either. It reflects rather an approach to rocks as the monuments of geologic processes. In accepting the single-name nomenclature, we assume, whether we want to or not, that petrographic features have no geologic value, that each extrusive species is characterized by a wide range in mineral composition, and that there is no appreciable difference between rocks with the same chemical composition but with different mineralogic features (such as liparite and quartz porphyry). Such an approach is obsolete. The acceptance of a double-name nomenclature means a genetic (i. e.,historical) approach to extrusive rocks; it directs the student's thought to the genesis of a rock and to its subsequent geologic history.

Thanks to the improved methods of microscopic study (e. g., iron-content determination of dark-colored minerals; the degree of regularity in feldspars; paragenetic analysis, etc.), petrography has acquired new means of determining the history of a rock. It is possible that the time is not too far off when this history can be reconstructed from petrographic data. This genetic direction of the development in petrography must determine our approach to nomenclature: where there already are rock names with a definite genetic meaning, they should be retained. This is why we cannot agree with Ye. K. Ustiyev's suggestion to abandon the double-name nomenclature for extrusives; it expresses the genetic, geologic approach to rocks.

In conclusion, it should be noted that Ye. K. Ustiyev is not quite consistent in his rejection of the double-name nomenclature; he recommends the use of some of the names from the paleotypal series he disavows, namely porphyrite and quartz porphyry. This shows that the diversity of extrusive rocks, related to different post-formational conditions, cannot be fitted to the Procrustean bed of a single nomenclature, poor in terms.

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CHRONICLE

GENERAL SESSION OF THE SECTION OF GEOLOGIC-GEOGRAPHIC SCIENCES (O. G. G. N.) ACADEMY OF SCIENCES, U. S. S. R., FEBRUARY 22-23, 1960[1]

by

S. D. Adrashnikova

The current General Session of the Section was devoted to the report on its 1959 activity, the election of Academic Secretary, the Section Bureau, and Directors of some of its organizations. Heard and discussed in this session were reports on some current problems and on the scientific research schedule of the Section.

Participating in the General Session were Academicians and Corresponding Members, in their capacity as members of the Section, collaborators in organizations of the Section's system and affiliated organizations of the Academy, as well as representatives of the Ministry of Geology and Mineral Conservation, universities, and other schools of higher learning.

Academician D. I. Shcherbakov, Academic Secretary of the Section, read a report on "Scientific Results of the 1959 Work of Organization of the Section of Geologic-Geographic Sciences."

He stated that the 1959-1956 Seven-Year Plan for the development of the state economy of the U. S. S. R. places great problems before us. During the period of the building of communism, Soviet science has become a great power with a broad scope of activity in the study of nature, and in the economy and culture of our country.

D. I. Shcherbakov also enumerated the most momentous problems in geology and geography considered by the Section and its Organizations in 1959. An analysis of these projects shows that scientific groups of geologists and geographers are able to solve large and important problems, which is the essence of the activity of academic institutions.

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[1]Obshcheye sobraniye Otdeleniya Geologo-Geograficheskikh Nauk Akademii Nauk SSSR, 22-23 Fevralya 1960 g.

With regard to observations that geology as a science is not being developed and that it has become purely applied, at its present level, the speaker explained that this has resulted from the lack of publications where geologists could set forth their theoretical as well as practical achievements, rather than by the lack of achievements themselves.

Thus, well established in Soviet geologic science is the principle of a progressive, irreversible development of the earth, as viewed across geologic time. This principle rejects metaphysical concepts prevailing in foreign geology. The principle of actualism, in its Lyellian sence, has lost its progressive meaning of the nineteenth century when Charles Lyell came forward against the catastrosphism theory of G. Cuvier. Students are now in possession of facts on the development of the earth's crust. On the basis of these facts, they have a chance to work out a theiry of geologic development of our planet. Where "pre-Lyellian" and "Lyellian" periods can be recognized in the history of geology, Soviet geology represents a "post-Lyellian" period of development.

In considering the subject of scientific work in the field of geology, now in progress in the Section's organizations, D. I. Shcherbakov singled out some of them, as follows:

1. Very important are the results obtained in subdividing the Precambrian, by stratigraphic study and by absolute-age determination. Noteworthy are the ideas advanced by N. S. Shatskiy on the significance on the Rhiphean stage (for the volume of the system) in the tectonic development of the earth's crust, as well as S. N. Vaumova's biostratigraphic study of Rhiphean deposits, thanks to which the lower limit of the application of biostratigraphic methods has been lowered to include very ancient formations.

The work of age laboratories which has yielded a number of age figures on the basis of study of glauconite in sedimentary rocks and of mica in igneous rocks, has led to important geologic conclusions, such as the duration of the late Precambrian continental period in the

Corresponding Member AS U. S. S. R., V. V. Belousov, while approving the attempt of the O. G. G. N. organization to develop physical, chemical, and other methods of geologic study, voiced the opinion that transferring the Institute of the Physics of the Earth to O. G. G. N. will not achieve the results expected, because the scientific interests of its staff lie on the whole beyond the scope of geology. However, the problem of the development of the earth, from its core to the crust, has been intensively studied in the Institute; for this reason, close cooperation between geologists of the two organizations should be fruitful for the science of geology.

Prof. V. G. Kort spoke on the development of oceanographic work and the great interest in the oceans of the world, both here and abroad. It appears that geophysical, geochemical and experimental methods of study are becoming as important in oceanography as they are in other geologic and geographic disciplines. Because of that, and in opposition to V. V. Belousov, V. G. Kort believes that the Institute of the Physics of the Earth should be transferred to O. G. G. N., where the study of our planet should be concentrated under a single direction.

In the opinion of the next speaker, F. A. Makarenko, Doctor of Geol. -Min. Sc., the directorates of the Institute and the Section do not properly champion the cause of geology by splitting it into theoretical and applied disciplines. Geologists in all fields must develop new ideas, and chart new trends, while delegating specific problems to industrial scientific-research institutes. In this connection, the Hydrology Laboratory has earmarked such problems as 1) water equilibrium in the subsurface hydrosphere; 2) regularities in geochemical evolution of the main genetic types of ground water; and 3) the role of ground waters in geochemistry.

Corresponding Member AS U. S. S. R. M. F. Mirchink disagreed with V. V. Belousov on the subject of the transfer of Institute of the Physics of the Earth to O. G. G. N. He is for the transfer there of the Paleontologic Institute, as well; he believes that both organizations in question are now outside of the O. G. G. N. because of an historic accident which had nothing to do with science.

Academician N. S. Shatskiy concurred with M. F. Mirchink. He stated that O. G. G. N. will acquire its proper stature when it will have united under it the Geophysical, Geochemical, and Paleontologic Institutes, perhaps not the same ones now operating in other divisions of the Academy but dealing with their proper problems.

Corresponding Member AS U. S. S. R. A. A. Amiraslanov noted that the 1959 report of the Academic Secretary had dealt mostly with problems of general geology and tectonics while devoting little attention to those of ore making.

Corresponding Member, AS U. S. S. R. L. V. Pustovalov emphasized the value of sedimentary minerals in industry, especially in connection with the current Seven Year Plan. In recent years, voluminous material has been compiled in the study of sedimentary rocks carrying, among others, a large amount of uranium mineral raw material (67% of all uranium is produced from sedimentary deposits in capitalist countries), also of power-producing minerals, such as oil, gas, and coal; and a number of precious dispersed elements. Principal projects scheduled in the Seven-Year Plan are connected with the utilization of sedimentary minerals (Kursk Magnetic Anomaly, Nikopol', etc.).

In order to digest the vast material on sedimentary rocks, it is necessary, in the opinion of L. V. Pustovalov, to speed up the organization of a special institute, in accordance with a resolution of the general session of O. G. G. N., of about two years ago.

Academician I. P. Gerasimov stated that there has not been enough effort made in the current year toward an improvement in the working conditions of the Section and that those elected to direct O. G. G. N. should bend all effort toward eliminating the shortcomings noted in 1959. In agreeing with L. V. Pustovalov, the speaker categorically disagreed with V. V. Belousov's opinion on leaving Institute of the Physics of the Earth outside the O. G. G. N.

Corresponding Member AS U. S. S. R. P. F. Shevetsov asserted that, as correctly noted by F. A. Makarenko, O. G. G. N. has not promoted the highest theoretical interests of science in recent years. He cited as an example, the lack of criticism of J. Bernal's statement on the status and prospects of geology. Nor had there been any advantage taken of the Conference on the Philosophy of Natural Sciences which tackled for the first time the problem of geologic movement, the one which F. Engels had not included in his discussion on the state of matter, in his unfinished work, The Dialectics in Nature.

Academician A. L. Yanshin stated that Soviet geology has achieved a great development on a broad regional scale, ranging out way beyond the boundaries of this country, toward results based on the data of world geology. These results are, in a number of instances, directly opposite to earlier concepts. It was believed for example, that contemporaneous horizons are characterized by similar floras and faunas. Now it has become obvious from more numerous data that the same sedimentary facies never (sic) carry the same faunal assemblages, even under the same conditions. This is another argument for transferring the Paleontologic Institute to O. G. G. N.

5. A study of regularities in the formation of frozen soils and rocks, ice, and snow; their utilization in the people's economy and elimination of their noxious effect (carried on by the Cryology Institute).

D. I. Shcherbakov pointed out that these substantial achievements of the Section and its several Institutes, expressed in the elimination of scattered, uncoordinated effort in their scientific plan, the concentration on most urgent problems, the improvement in personnel, a broadening of the experimental base, a considerable expansion in the activity of the Section Bureau in organizing international connections, in working out the most important scientific trends, in organizing coordinating and other conferences and meetings, all this does not excuse us from a further effort to bring out the full potential of the Section. It should be kept in mind, however, that there are many difficulties connected with the abundance of branches and fields of activity, which accompanies the subdivision of geologic science and its practical applications.

Thus, our scientists are constantly called upon to perform "scientific service" in the field of geochronology, stratigraphy, lithology, prtrography, mineralogy, mining geology, seismic studies, volcanology, Quaternary geology, etc. These individualized branches of geology should be developed continuously, in direct proportion to the development of current problems. At the same time, there is a reverse tendency, the posing of complex problems, insoluble without the participation of allied disciplines. Thus new disciplines are created on the borderline of two or more disciplines, by their union. Geochemistry and geophysics are comparatively recent disciplines; astrogeology is being born. It is essential, therefore, to devise a correct organizational setup for coordinating the development of new branches of science with a consideration of general problems.

There was a considerably improvement in the work of the Section's organizations, as compared with the preceding period: the scattering of effort was eliminated, with only 49 projects underway. Still, there was no proper concentration on the most important, in the planning of scientific effort. The work on these 49 projects is perhaps useful as far as the general progress of science and the daily "scientific service" are concerned, but this situation is hardly conductive to a fulfillment of basic demands of the Seven-Year Plan. It appears from resolutions of the Twnety-First Congress of the Communist Party of the Soviet Union, that the time element is most important. For that reason, priority must be given to those projects which will bring the quickest and most tangible results in the national economy, rather than to a general advancement of the scientific front.

It is necessary to reorganize the work of academic institutions so that the work direction would be exercised by projects rather than by divisions, as has been the case. In this connection, there is merit in the idea of transferring to the Section of Geologic-Geographic Sciences of some other institutions from other divisions, such as Institute of the Physics of the Earth and the Paleontologic Institute.

Among the current momentous tasks is the intensification of coordinating effort, both in the relations of the Section's institutes with the corresponding organizations in other divisions, and the Academies of union republics and the state economic organizations (Ministry of Geology and Mineral Conservation, Glavgeologiya R. S. F. S. R., Gosplan S. S. S. R., etc.). At the same time, a better coordination of theory and practice is achieved by diversified information: publication of appropriate bulletins along with the established method of diverse conferences and sessions.

Such problems as a broader utilization of physical and chemical methods, a strengthening of the experimental base, and consequently the corresponding enlargement of the working plant of O. G. G. N. are still urgent for our organizations.

In conclusion, D. I. Shcherbakov stated that the Section Bureau had designated the following projects as most important in the fulfillment of the Seven Year Plan:

1. A study of the structure, composition, and development of the earth, and the origin of industrial minerals and regularities in their distribution in the earth's crust, which is a broader treatment of the main geologic problem of the current year, that of regularities in the distribution of such minerals, alone.

2. The interior structure of the earth's crust, the interior heat, igneous activity, and ore-making processes. This project has been advanced to strengthen the ties with other divisions of the Academy and with industrial geologic organizations. It is to be solved by deep drilling and geophysical, geochemical, and experimental methods; it also raises the question of super-deep drilling.

These projects conform to demands of the Seven Year Plan; their efficient development will promote a broadening of the mineral raw-material base, a qualitative improvement of the latter, and a rational distribution of industry.

The next speaker was Corresponding Member As U. S. S. R. S. V. Kolesnikov. He reported on the value of the Limnology Laboratory with its highly qualified staff who had produced many interesting results in their comprehensive study of lakes.

uropean U. S. S. R., and of other conditions of ologic development in the periphery of the ltic Shield with its relicts of sedimentary and etamorphic formations (Kola Peninsula).

2. Broadly developed in the current year was e most important problem of "Regularities in e Distribution of Mineral Deposits". A large umber of subjects were taken up within the ope of this topic. For that reason, the single ommission directing this work had to be split to five: exogenetic deposits (Academician N. S. hatskiy, Chairman); endogenetic deposits (Prof. . A. Sokolov, Chairman); coal (Corresponding ember AS U. S. S. R. I. I. Gorskiy); oil and as (Corresponding Member AS U. S. S. R. M. F. irochink); rare and dispersed minerals (Corresponding Member AS U. S. S. R. K. A. Vlasov). hese commissions are united under the Interdepartmental Board; together, they perform the reat task of coordinating the work on a given roject. Incidentally, our way of working on e problem of "Regularities in the Distribution f Minerals" has been adopted by geologists of ther Socialist countries, such as the Chinese eople's Republic, People's Republic of Bulgaria, oland, Czechoslovakia, and others.

Data of maps of the actual and probable disribution of various groups of raw mineral aterial in the earth's crust, the main source f information for this project, were used in the asic solution of the problem of interrelationship etween tectonics, igneous activity, and minerlization (in the endogenetic cycle) and between ectonics and the formation of stratified units nd sedimentary sequences (in the exogenetic ycle). The many facts at their disposal enbled students to consider the distribution reularities of minerals from a broader point of iew.

Inasmuch as the results of study of regional rmation conditions have been adopted as a asis for discerning the regularities in mineral istribution, deep and super-deep as well as urficial, it can be stated that geology has closed e gap between theory and practice and that scintific problems are treated with an eye to their ractical significance. Thus, a number of disoveries have been effected, important in the conomy of our country (oil in the Ukraine and econd Baku; diamonds of Yakutia; new deposits f potassium salts; fresh artesian waters in eserts of the U. S. S. R.; etc.), precisely beause of accurate scientific forecasts.

3. The current period witnessed a substantial evelopment of the theoretical views of N. S. hatskiy on paragenetic relations of rocks (see s paper in Izvestiya AS U. S. S. R., geol. ser., o. 5, 1960 — Edit. Board). N. S. Shatskiy onsiders the problem of facies combinations nd facies series of sedimentary and volcanic its within various formations. This made it ossible to discern the paramount regularities in facies changes and geologic relationships of adjacent formations as well as in the parallel occurrence of rocks and minerals of different origin.

It is important to note that the theory of geologic formations is broadly used in studies connected with regularities in the distribution of sedimentary industrial minerals in the earth's crust. As an example of such efficient application of the facies analysis method, the speaker cited the study of regularities in the distribution of such industrial minerals as oölitic iron ore, jaspilite, and salts.

4. Extensive work on the tectonic map was done by a special commission of the Section, in 1959, under the direction of N. S. Shatskiy. The compilation of a 1:2, 500, 000 tectonic map of Europe, undertaken at the initiative of Soviet geologists, is almost completed. On this project, Soviet geologists had to work with material not only from various regions of the U. S. S. R. but from a number of foreign countries as well (Ye. B. Pavlovskiy and A. A. Bogdanov, on the tectonics of France; M. V. Muratov, Albania and the Alps; and Yu. M. Pushcharovskiy, the Arctic sector).

D. I. Shcherbakov also noted a new trend pursued by the Section's organizations in the field of geography. At the present time, geographers do not confine their study to the relationship between various natural factors. The most important problems of modern geography are the role of man in modifying nature, a survey of natural resources, and working out conservation methods. This task is dictated by the practice of building up the national economy and by the development of science.

In this connection, the speaker reviewed the main projects underway in Geographic Institutes (members of the Section of Geologic-Geographic Section system), such as the following:

1. The thermal conditions of the earth's surface and their significance in the dynamics of natural processes closely related to practical problems of beneficiation and hydrotechnical and mining construction.

2. Geographic description of economic regions of this country.

3. Geography of foreign lands. The Geography Institute has published a number of descriptive monographs; in some instances the work was done in cooperation with Chinese, Roumanian, and Bulgarian geographers.

4. A study of the oceans of the world with regard to its resources, food, chemical, and energy, for the purpose of their utilization in the people's economy (carried on by the Oceanology Institute).

A. L. Yanshin reported that as early as 1952 the Conference on Sedimentary Rocks had recognized that the earth's development is not expressed in simple but rather in qualitative processes taking place within and on the earth's crust. The current problem before Soviet geologists is to develop this theory of a qualitative development of the earth on a high theoretical level.

Academician K. I. Satpayev noted that O. G. G. N., despite its large staff of outstanding geologists and other scientists, has not been used at its full potential, either in applied fields or on the theoretical leve. On the theoretical level, most work has been done on material from peripheral organizations, such as the Commission on Regularities in the Distribution of Industrial Minerals. He believes in the necessity of consolidating the work in all fields of geology, geophysical, geochemical, and paleontologic, because the full value of a result cannot be realized without a comprehensive study of geologic objects.

On the basis of the report by Academic Secretary D. I. Shcherbakov and its discussion, the General Session of O. G. G. N. has adopted an appropriate resolution. Some of its points are as follows:

1) To petition the Presidium of the AS U. S. S. R. for a reorganization of O. G. G. N. as the Section of Geologic-Geographic and Geophysical Sciences, with the transfer to it of Institute of the Physics of the Earth and the Atmosphere, Marine Geophysical and Geochemical Institute, and of Geochemical and Paleontologic Sections of other institutes.

2) To petition the Academy Presidium for granting more working space to now overcrowded organizations, with priority given to Institutes of Geography, Oceanography and, Cryology, and the Leningrad geologic-geographic laboratories.

3) Publications by the members of the Section for the promotion of geologic-geographic sciences.

4) Intensification of the study of sedimentary ore deposits, by the Section staff.

The following speakers were heard after the discussion of the report on the 1959 activity of O. G. G. N.:

1. Academician A. A. Polkanov: Geochronology of the Baltic Shield.

2. Corresponding Member AS U. S. S. R. G. D. Afanas'yev: Study of the Deep Structure of the Earth's Crust.

3. Yu. M. Pushcharovskiy, Doctor of Geol.-Min. Sc.: Tectonic Map of the Arctic.

4. Academician I. P. Gerasimov: Scientific Results of the Third Session of the U. S. S. R. Geographical Society.

5. Corresponding Member AS U. S. S. R. N. G. Kell': Value of Aerial Methods in Geologic-Geographic Studies.

Participating in the discussion of these papers were Academician N. S. Shatskiy, Corresponding Members AS U. S. S. R., G. D. Afanas'yev, A. G. Vologdin, V. V. Belousov, N. A. Tsytovich, Doctor Geol.-Min. Sc. A. T. Donabedev, Academician A. L. Yanshin, and Corresponding Member S. V. Obruchev. They emphasized the urgency of problems under discussion and the necessity for further study. The paper of G. D. Afanas'yev is published in this issue (see p. 3); the others are to follow.

In the election which followed, Academician D. I. Shcherbakov was again chosen as Academic Secretary of O. G. G. N. Elected as members of the Section Bureau were Academicians D. I. Shcherbakov, A. A. Grigor'yev, (First Deputy Academic Secretary), I. P. Gerasimov, D. S. Korzhinskiy, K. I. Satpayev, A. A. Trofimuk, N. S. Shatskiy, A. L. Yanshin, Corresponding Members Kh. M. Abdullayev, A. A. Amiraslanov, G. D. Afanas'yev, I. I. Gorskiy, K. A. Vlasov, L. A. Zenkevich, M. F. Mirchink, V. I. Smirnov, F. V. Chukhrov, Professors G. A. Avsyuk, V. G. Kort, P. A. Shumskiy, and V. F. Solov'yev (science secretary).

Professor V. G. Kort was also elected Director of the Oceanography Institute, and Professor V. V. Mokrinskiy, Director of the Laboratory of Coal Geology.

COMPILATION OF AN INTERNATIONAL GLOSSARY OF COAL PETROLOGY[2]

by

I. E. Val'ts and I. B. Volkova

The first meeting of the International Conference on Petrology of Coal, organized following a 1951 resolution of the Third Congress, on Carboniferous Stratigraphy and Geology, was held in Heerlen (the Netherlands), in 1953. An International Nomenclature Commission was elected from the members of the Committee; it was charged with the task of compiling and describing all terms relating to the petrology of coal in use in various countries. Thus began the work of compiling an International Glossary of Coal Petrology.

[2] O rabotakh po sostavleniyu Mezhdunarodnogo Slovarya po Petrologii Ugley.

The first series of terms on the petrography of coal was accepted and published by the International Committee on Coal Petrology in Liège, 1955. The Soviet participants on the Committee were I. I. Ammosov and A. A. Luber. The first edition of the Glossary, published in 1957, included mostly terms of applied petrography.[3]

The international glossary is a card file in three languages: French, German, and English. Each term is explained on separate cards, many of which are illustrated. A descriptive term is arranged as follows: the origin of the term, optical properties of the component in transmitted and reflected light, density, microhardness, etc., the mode of occurrence, and practical use.

It should be noted that the characteristics of terms given in the Glossary are a result of comprehensive discussion in the course of which the representatives of various countries had to make necessary and important concessions. The classification of petrographic aspects of coal turned out to be the most difficult and controversial.

The following grouping for petrographic components of coal was adopted by the International Commission:

1. Microscopic components, i. e., lithotypes: with suffix en (ain); they correspond on the whole to M. Stops' ingredients, vitrain, clarain, durain, and fusain.

2. Microscopic components visible only under the microscope; they are differentiated into two categories:

a) macerates, the simplest microscopic elements with a suffix init (inite), collinite, telinite, etc.;

b) characteristic associations of macerates (microcomponents) making up bands over 50 microns thick, microlithotypes with suffix it (ite), vitrite, durite, etc.

It should be noted that the corresponding names are different in the U. S. S. R.: ingredients of lithotypes; microcomponents of macerates; and microingredients of microlithotypes. The term "petrographic type", widely used in Soviet coal petrography, is missing in this classification.

After publication of the first edition of the Glossary, the work of processing new coal petrographic terms continued for the second edition. Another meeting of the Commission on Nomenclature was held during the First International Congress on Coal Petrology, at Heerlen, in 1958. At the suggestion of I. I. Ammosov, the Commission resolved to prepare several Soviet terms for the next edition.

A great deal of preliminary work was done by a group of Soviet coal petrographers under the direction of I. I. Amosov and I. E. Val'ts, during the first half of 1959, on the description of eight terms for the Glossary: semivitrinite, semicollinite, semitelinite, mixtinite, suberinite, polynite, algo-collinite, and algo-telinite. These terms are included in the nomencalure of petrographic components of coal for technologic purposes, adopted by the 1956 All-Union Conference of Coal Petrographers.[4] The terms processed by Soviets authorities on coal petrography were dispatched to the International Commission Secretariat which in turn dispatched them to the Commission's members for preliminary consideration.

A meeting of the Nomenclature Commission (subcommittee) of International Committee on Coal Petrography was held in London, September 1959. Its agenda was as follows:

1. Approval of the definition of twelve terms processed by the Heerlen editorial board in 1958.

2. Discussion of the eight terms from Soviet nomenclature mentioned above, some American terms (attrite, lustrous coal, type, subtype, opaque substance), and of such general terms as coal, degree of metamorphism (rank), mineral impurities in coal; coal horizons, resin bodies in coal, etc.

3. Topics dealing with second edition of the Glossary.

4. Correlation with terms of petroleum geology.

5. Selection of new terms for the Glossary.

According to a communication from Prof. R. Noël, Secretary of the Commission, much has been accomplished in the London meeting, including a detailed discussion of Soviet nomenclature. Six out of the eight Russian terms were approved for publication, with slight editorial corrections: semivitrinite, semicollinite, semitelinite, mixtinite, polynite, and subernite. Two terms, algo-collinite and algo-telinite, were temporarily put aside pending additional study and correlation with their original definitions by M. Stops and S. A. Seyler.

It is the belief of the Nomenclature Commission that the term "alginite" unites the

[3]Le glossaire international de pétrologie des charbons, Paris, 1957.

[4]Resolution of the All-Union Conference of Coal Petrographers at the Institute of Fossil Fuels A.S. USSR., Moscow, 1956.

macerate group (microcomponents), in the same way as the term "vitrinite" unites the macerates collinite and telinite. For a better differentiation of terms "humus coals" from sapropelites, the Commission suggested that Soviet coal petrographers consider the possibility of substituting the terms teli-alginite and colli-alginite for algo-telenite and algo-collinite, respectively. So defined, the group of terms, alginite, teli-alginite, and colli-alginite, would form a unit not to be confused with the corresponding terms for humus coals.

The international Commission had high praise for the color and black-and-white microphotographs attached to the description of microcomponents.

English scientist, Professor G. Fenton was elected Chairman of the Commission, to take place of the late Prof. M. Legraye; Belgian Professor R. Noël was reelected Secretary. The next session of the International Commission of Coal Petrography has been scheduled for June 1960, in Madrid, Spain.

Its agenda is as follows:

1) approval of the terms coal, humus coal, degree of metamorphism, mineral impurities, study methods, historical reference, resin bodies in coals, sporangis, algae, and natural coke.

2) consideration of terms submitted by the American coal group: coal constituent, component, subtype, and lustrous coal.

3) approval of Russian terms, algonite and subernite.

The compilation work for an International Glossary of Coal Petrology is important both theoretically and practically, especially in connection with the growth of this discipline in various branches of industry. In the Soviet Union, because of the exceptional variety of coal and the broad scope of petrographic study of coal, there are several current nomenclatures and classifications of microcomponents and types of coals. One of the urgent tasks of Soviet coal petrographers is a further processing of coal petrographic terms for publication in the International Glossary. The scientific cooperation of coal petrographers from different countries will promote the development of coal petrography and strengthen international friendship.